

DISSOLVED OXYGEN
OBJECTIVES WORKSHOP
TECHNICAL PROCEEDINGS
December 12, 1989





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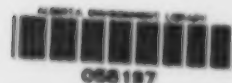


Alberta

Environmental Protection Services
Environmental Assessment Division
Standards Research and Development Branch

Edmonton, Alberta

56197





FOREWORD

Dissolved oxygen continues to be the single most frequently used indicator of water quality in rivers and lakes. The significance of dissolved oxygen in sustaining healthy aquatic life is universally recognized. On December 12, 1989, a technical workshop was held to focus on the use and application of the dissolved oxygen water quality parameter with respect to several issues. These included ambient objectives and guidelines, monitoring of Alberta river and lake systems, analytical measurement, regulation and modelling of conventional biochemical oxygen demand point-source loadings, fisheries protection, physiological responses, and research needs based on data gaps. This publication is a consolidation of the papers and notes which comprise solely the views of the respective authors attending the workshop. Alberta Environment neither approves nor endorses the conclusions expressed herein, which are the responsibility of the authors.



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APPLICATION OF THE CCREM GUIDELINE FOR DISSOLVED OXYGEN TO A
WATER QUALITY OBJECTIVE TO PROTECT AQUATIC LIFE

by

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1. THE PURPOSE OF THE CCREM GUIDELINES

The CCREM (1987) guidelines were prepared for the Canadian Council of Resource and Environment Ministers which included all provincial and federal Ministers. The guidelines document was prepared by the Task Force on Water Quality Guidelines. This task force, made up of provincial, territorial, and federal government representatives, was established by CCREM in 1983. The Water Quality Branch of Environment Canada, Ottawa, acted as the co-ordinator and editor overseeing the project. The guidelines are the result of the cooperation of the two levels of government. As such, they are Canadian and not specifically federal, although they are used by Environment Canada and the Department of Fisheries and Oceans.

The CCREM guidelines are not enforceable standards. They are recommendations. The preface to the guidelines which was written by Environment Canada emphasizes that they "do not constitute values for uniform national water quality and that their use will require consideration of local conditions." The guidelines contain an appendix explaining how they can be used to develop site-specific objectives. The appendix states that "many of the guidelines . . . will be modified, when used to formulate water quality objectives, to account for site-specific variation in conditions. The guidelines should, therefore, not be regarded as blanket values for national water quality."

The CCREM guidelines were developed to harmonize the guidelines throughout Canada and to provide basic scientific information. The approach was to use, or modify, existing guidelines after ensuring that they would be appropriate to Canadian conditions and would reflect the recent scientific literature. The CCREM guideline for dissolved oxygen was based on the US EPA criteria published in 1986 since the US document included a thorough updating of the literature and appeared to provide adequate protection for Canadian fish species. (However, some of the concepts of the US EPA were not accepted). The CCREM guidelines are intended to protect Canadian aquatic life if applied directly in the absence of specific water quality objectives. They were also intended to form a common basis for the development of provincial or basin-specific objectives.

2. THE ASSUMPTIONS OF THE CCREM GUIDELINES

The guidelines for dissolved oxygen are based on the US EPA criteria which were developed primarily from growth data and information on temperature, disease and pollutant¹ stress. Each guideline represents values between no production impairment and slight production impairment. They are estimates of the threshold concentration above which there is no negative effect but below which chronic negative effects have been documented.

The intention of the guidelines for dissolved oxygen is to protect all life stages over indefinite exposure to the water. If these guidelines are applied to a 7Q10 prediction of water quality, the 7Q10 case would be treated as if it occurred continuously. This would be a conservative assumption.

The dissolved oxygen concentrations in the US EPA (1986) criteria are intended to be protective at typically high seasonal temperatures. These high seasonal values are higher than the temperature of the laboratory tests which are usually done at the specie's optimum temperature which is often about 15°C. As such, the criteria are intended to protect fish where the critical period of oxygen stress and production impairment could occur in August.

The guidelines are expressed in terms of the actual amount of dissolved oxygen available to organisms in milligrams per litre (mg/L). The US EPA (1986) considered criteria expressed as a percent saturation unnecessarily stringent in the cold months and potentially unprotective during periods of high ambient temperature or at high elevations. (Oxygen partial pressure is subject to the same temperature problems as percent saturation).

In the rivers and lakes of Western Canada, dissolved oxygen usually becomes limiting at extreme temperatures, either under ice cover at temperatures below 5°C or at high summer temperatures when dissolved oxygen reserves in the water body cannot meet the increased metabolic demand of the entire aquatic community. (Laboratory results which are commonly expressed as percent saturation or partial pressures are, for the most part, not conducted at the extremes.) The concerns expressed by the US EPA were considered relevant to the Canadian situation.

At high ambient temperatures, a guideline based on a constant partial pressure or percent saturation such as 50% would not be protective. Davis (1975a,b) emphasized that fish require both the correct oxygen tension gradient to move oxygen into the blood and a

¹ The effect of reduced dissolved oxygen on the toxicity of specific pollutants was not considered.

sufficient quantity of oxygen (which could be measured in mg/L) to fulfill the requirements of metabolism. As temperature increases, the metabolic requirements increase while the concentration of oxygen in the water decreases for any given percent saturation. Davis (1975a) calculated criteria values for oxygen content in mg/L which he later converted to percent saturation as his final units. At high temperatures, the quantity of oxygen needed to provide the necessary oxygen content dictated higher percent saturation values.

At very low ambient temperatures, the metabolic rate of fish drops to a very low level while the oxygen content of the ambient water at air saturation becomes very high. The result is a surplus of oxygen above the quantity required for active metabolism. The active metabolic rate (i.e., the level of oxygen uptake accompanying maximal swimming activity) of yearling sockeye salmon, for example, drops from about 13 ppm to 5 ppm when the temperature decreases from 20°C to 5°C (Brett 1964). The ambient dissolved oxygen needed to maintain the optimum oxygen tension gradient between the ambient water and the fish tissues can be established, thereby ensuring maximum delivery of oxygen to the tissues. Oxygen saturation of the blood can be measured and a reduction in oxygen shown as an effect. However, when the metabolic demand of the tissues is greatly reduced by cold temperature, the overall effect on the growth and development of the fish may be less than the effect on the oxygen tension gradient. In setting an objective, the quantity of oxygen required for metabolism must be considered as well as the oxygen tension gradient, especially at extreme temperatures.

Unfortunately, there is very little information on the effect of oxygen¹ on growth, or sublethal effects at cold temperatures. When he graphed the effect of temperature on the incipient sublethal response thresholds for all the freshwater fish data available to him, Davis (1975a) was only able to include one data point below 5°C. Although percent saturation values can be extrapolated to lowest temperatures, actual data on the resultant effect on important fish characteristics such as growth effects are needed. When examining growth rate, the US EPA (1986) found that the highest thresholds for growth effects occurred at high temperatures. They were unable to present adequate cold water data. They reported two tests at 8.5°C where the reduction in growth rate at 4 mg O₂/L was relatively minor. At higher temperatures, growth rate would be severely reduced at 4 mg O₂/L. The US EPA (1986) concluded that dissolved oxygen levels down to 5 mg/L probably had little effect on salmonid growth rate when temperatures were below 10°C.

¹ Cold temperature also has a direct effect on fish, particularly on their sustained swimming performance.

In many Alberta lakes and rivers, annual dissolved oxygen minima occur during late winter under ice cover. Near 0°C, rates of growth for fish are normally low. Thus, the effects of low dissolved oxygen concentrations during winter on annual growth would also be lower than if the dissolved oxygen minimum occurred in summer.

It was recognized from the beginning that many waters in Canada do not naturally meet these guidelines. The CCREM guideline for dissolved oxygen cautioned that the natural variations of dissolved oxygen concentrations in ambient water must be taken into account. The populations of fish that inhabit these waters are presumably adapted to these less-than-optimum conditions. In this case, the site-specific objective could be lower than the guideline value. The problem is that less-than-optimum conditions are often partly the result of gradual increases in anthropogenic BOD loading over time rather than natural conditions. The historical record would have to be examined to see if the natural condition of the river can be determined.

The intention of the guidelines is to protect the entire aquatic community. Fewer data are available on the effects of low dissolved oxygen on freshwater invertebrates. If, however, all life stages of fish are protected, the invertebrate communities should also be reasonably protected, although they may not be unchanged (Davis 1975b). The dissolved oxygen requirements for the survival of some species of aquatic insects, especially insects from mountain streams, are almost certainly greater than those of most fish species (US EPA 1986). Thus, the guidelines may not protect every aquatic species.

The guidelines were subdivided into early life stages because the dissolved oxygen requirements of fish vary with their life stage and the most sensitive life stages often occur for a relatively short period of time. This approach allows for a lower guideline for much of the year, but it does require more field studies to determine what species and life stages are present.

The CCREM guideline for the early life stages applies from spawning through to 30 days after hatching. However, the dissolved oxygen required so that no delay in development or hatching occurs is not uniform over time. Requirements of chum salmon eggs at 10°C, for example, increased during development from less than 2 mg/L shortly after the eggs were laid to 7.2 mg/L just prior to hatching (Alderdice, Wickett, and Brett 1958). Thus, objectives could define the early life stages more narrowly to include only the sensitive stages.

The guidelines are also divided into warm and cold water species. Most of the supporting data available are about salmonid species, primarily trout and salmon. Thus, most of the information about cold water fish is actually about these salmonid fish. Some non-

salmonids such as northern pike may prove to be at least as sensitive to low dissolved oxygen as salmonids (Siefert et al. 1973). The US EPA Criteria document lists pike, sculpins, smelts, and herrings. Anecdotal information suggests that cool water fish are more sensitive to low dissolved oxygen than warm water fish. Thus, cool water fish should be included with the cold water species in the absence of specific information to the contrary.

I believe it is possible to set a site-specific objective of less, or greater, than 6.5 mg/L within the intent of the CCREM guidelines if additional biological studies are conducted to show that the life stages present, when dissolved oxygen levels are predicted to be low, have dissolved oxygen requirements less, or greater, than the guideline value. Objectives could also be set higher than the guidelines to provide a high degree of protection for important stocks of sensitive salmon or trout species.

3. THE DISSOLVED OXYGEN GUIDELINE

The guideline for the minimum dissolved oxygen concentration to protect warm water biota is 6 mg/L for early life stages and 5 mg/L for other life stages. Some species such as white sucker may require much less, even in the early life stages (Siefert and Spoor 1974).

The guideline to protect the early life stages of cold water biota is 9.5 mg/L in order to provide a minimum of 6.5 mg/L of dissolved oxygen in the water adjacent to salmonid eggs buried in the gravel. The 9.5 mg/L actually applies only to a special case, since not all cold water fish bury their eggs. The minimum level of dissolved oxygen to be present at the eggs surface is the same as the level recommended for other life stages, 6.5 mg/L.

The dissolved oxygen concentration in the interstitial water of gravel of the spawning bed was considered by the US EPA (1986) to be at least 3 mg/L lower than the oxygen concentration in the overlying water column. Therefore, 9.5 mg/L was calculated to accommodate routine sampling methods; the concentration of importance to the salmonid eggs is 6.5 mg/L. Both numbers are placed side by side in the guideline. The 3 mg/L was chosen arbitrarily based on a salmon study and a trout study (US EPA 1986). The results of these and other studies show that dissolved oxygen concentrations vary widely (from 5 to 6 mg/L) within each redd (Koski 1965) and between redds.

Several field studies support the US EPA criterion of 6.5 mg/L. Sowden and Power (1985), conducted a spring field study of rainbow trout embryos under ambient spring temperatures in Southwestern Ontario, which provides a qualitative validation of the US EPA criteria. They found that, at mean intergravel dissolved oxygen concentrations of 6.9 mg/L or

higher and water velocities greater than 15 cm/h percent survivals were in the order of 21 to 22%. At 6.0 mg/L, the percent survival dropped to 9.6% at the same velocity. Temperatures were not provided in the paper. Survival of embryos was negligible until mean dissolved oxygen concentrations exceeded 5.2 mg/L. Turnpenny and Williams (1980) also observed no survival of rainbow trout at mean dissolved oxygen concentrations less than 5 mg/L.

Larval fish are also affected by low oxygen levels. Miki-forov (1952) reported better growth and yolk sac absorption in 5-day-old salmon larvae reared for 25 days at 6.8 to 7.5 mg O₂/L compared to those reared at 4.5 to 5.0 mg O₂/L.

Generally, there seems to be a difference at least 1 mg/L between the results of field studies where oxygen levels and other factors vary and the results of carefully controlled laboratory studies where virtually all stress is eliminated. In fact, a laboratory study by Brett and Blackburn (1981) showed that, at 5 mg/L, dissolved oxygen was no longer a limiting factor in the growth of salmon eggs. These results are in stark contrast to the field results that show complete mortality at the same level.

The most recent guidelines for the protection of juvenile and adult fish from the US EPA (1986) and CCREM are based primarily on growth rate as a measure of fish production impairment. As growth is an expression of the net product of metabolic functions, it is a good indicator of an overall effect of low oxygen (Davis 1975b). The US EPA (1986) reported that apparent reductions in growth rate is usually severe at concentrations of 4 mg/L or less. The reduction in growth rate in the intermediate range is moderate to slight if the exposures are sufficiently long. Growth data for northern pike (Adelman and Smith 1970) were the best available for non-salmonid cold water fish. At 5.4 mg/L of dissolved oxygen, a slight growth impairment of 5% was found at 19°C.

4. APPLICATION OF THE GUIDELINE TO THE ATHABASCA RIVER

Dissolved oxygen levels in the Athabasca River are predicted to be lowest in late winter (February-March). HydroQual, using the Alberta Environment model, estimated Athabasca River dissolved oxygen concentrations for various BOD loadings during ice cover. With all five proposed pulp mills discharging BOD at 3.0 kg/adt, estimated river dissolved oxygen concentrations were as low as 5.0 mg/L. The critical reaches during ice cover are upstream from the confluence of the Lesser Slave River, and upstream from Grand Rapids.

Dr. McCart, in his 1989 testimony to the Alberta-Pacific Environmental Impact Assessment Review Board, indicated that there is very little information on the fisheries in this reach. He identified

the following as potential impacted species: lake whitefish, an important fall-spawning species found below the Grand Rapids, and which may spawn above Grand Rapids; mountain whitefish, which may spawn in the reach above the Grand Rapids; and burbot, which are a winter-spawning species. Other species that may be there would likely be spring-spawning species.

Wallace and McCart (1984) provide no information on the species of fish that may be present within this section of the Athabasca River; however, fisheries investigations conducted during September 1988 by Beak Associates on the Athabasca River at Calling River revealed a species assemblage typical of the well-studied section of the mainstream downstream from Fort McMurray (Alberta Pacific Forest Industries Inc. 1989). Pike, walleye, white suckers, and longnose suckers were captured at the Calling River. Several cyprinid species common to the lower section of the Athabasca are also expected to occur here, and arctic grayling and lake whitefish may be present on a seasonal basis (Scott and Crossman 1975). No studies have been done on possible fish movements from the Athabasca River into Lac La Biche, although there have been reports of grayling in Lac La Biche that probably originated in the Athabasca River.

I would like to use the Athabasca River example as a case study for the application of the CCREM guidelines.

In the absence of information on the species and life-stage of fish that are present, the conservative position would be to apply the guideline for cold water biota, early life stages to the entire length of the river throughout the year. This is the position adopted by the Department of Fisheries and Oceans and the Department of Environment (1989) who quoted 9.5 mg/L. Winter dissolved oxygen concentrations in the Athabasca River are presently below this value upstream of Smith and at Athabasca (Morton and Shaw 1989).

The Athabasca River demonstrates immediately the need for supporting field data, particularly fisheries data, when applying the CCREM guidelines directly or when developing objectives. The criterion of 9.5 mg/L is very difficult from a river management point of view.

If the only salmonids spawning in the river in the fall are found to be lake whitefish and mountain whitefish as predicted by Dr. Peter McCart, then the criterion of 9.5 mg/L is not applicable since it is applied only to salmonid eggs found in the gravel. Whitefish are, I believe, broadcast spawners. The 3 mg/L used to arrive at the 9.5 mg/L has no scientific basis related to whitefish and 6.5 mg/L shown in brackets in the guideline should be used.

The information used to derive the dissolved oxygen guideline of 6.5 mg/L was predominantly based on trout and salmon species. I was unable to find equivalent information for lake whitefish. A test was done on mountain whitefish embryos by the US EPA (Siefert et al. 1974) in

laboratory test chambers with a flow of 3.5 cm/min and a temperature of 4°C. At 50% oxygen saturation (6.5 mg/L), both the survival and the development time required up to the start of hatching were similar to controls. At the next oxygen level studied (4.6 mg/L), however, the onset of hatching was delayed and the average percent survival dropped to 71% compared to 85% in the control. At 7°C, a concentration of 6.0 mg/L represents 50% oxygen saturation and results were equal to controls. (Results from this laboratory study should not be applied directly to the Athabasca River population of mountain whitefish because they are laboratory data and do not take into account field conditions at the sediment surface.) The Siefert et al. (1974) study supports the CCREM guideline; the guideline concentration of 6.5 mg/L should protect whitefish embryos if this concentration occurs adjacent to the eggs. I believe that a dissolved oxygen concentration of 5 mg/L would probably have a negative effect on early life stages.

If fisheries studies show that whitefish or other cold water fish are present in the river but do not spawn there, or do not spawn in certain reaches of the river, the guideline for other life stages would apply. This guideline is also 6.5 mg/L, but it was established to protect fish production, primarily growth, at high seasonal temperatures. The minimum dissolved oxygen conditions on the Athabasca River occur very closely to 0°C. There may be a valid scientific reason for setting a winter or cold water objective that is different from the guideline in this case.

I have concentrated on the winter low dissolved oxygen problem with respect to fish in the Athabasca River. Summer oxygen requirements of fish and oxygen requirements of other aquatic biota would also have to be considered in setting objectives for the river.

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DISSOLVED OXYGEN OBJECTIVES IN ALBERTA
(HISTORICAL PERSPECTIVE) AND OTHER JURISDICTIONS

by

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1. INTRODUCTION

Historically, dissolved oxygen has been and continues to be the single most frequently used indicator of water quality in streams and rivers. The presence and significance of dissolved oxygen to sustain healthy aquatic life is universally recognized. Oxygen dynamics in streams can be theoretically described by a mathematical equation or model to:

- predict the response of the oxygen resource to any stimulus (including pollution) before it occurs;
- assess the effectiveness of existing pollution control measures; and
- determine the degree of treatment required to maintain specified oxygen levels.

2. CALIFORNIA

In the Second Edition of the Water Quality Criteria, authored by McKee and Wolf (1963), for the California State Water Resources Control Board,

"Ellis (247,313) indicated that under average stream conditions, 3.0 mg/L of dissolved oxygen, or less, should be regarded as hazardous or lethal, and that to maintain varied fish fauna in good condition the dissolved oxygen concentration should remain at 5.0 mg/L or higher."

3. PRAIRIE PROVINCES WATER BOARD (PPWB)

In 1972, the Prairie Provinces Water Board (PPWB) adopted several recommendations of a Water Quality Task Force it established to study water quality management needs in the Prairie Provinces. These included the adoption of water quality objectives which had been developed jointly by the provinces of Alberta, Saskatchewan, and Manitoba. These objectives were intended to be applied to inter-

provincial streams under the administration of the Board. The objectives were published in March, 1973 by the PPWB with the understanding that they may be amended from time to time by mutual agreement.

With respect to dissolved oxygen, the Water Quality Task Force simplified the California criteria in terms of recommending "a minimum of 5 mg/L at any time."

4. ALBERTA

Concurrent with Alberta's participation in the activity of the PPWB's Water Quality Task Force Work, "Surface Water Quality Criteria, Province of Alberta" was prepared by the Water Pollution Control Section, Division of Environmental Health in August, 1970. This document replaced "Summary Surface Water Quality Criteria - Province of Alberta," first published in 1969.

On January 28, 1970, the Provincial Board of Health Regulations Respecting the Disposal of Waste Water and the Control of Water Pollution (Division 39) were adopted. These regulations provided the Provincial Board of Health with control of insecticides applied to water and the mechanism for the establishment of the Water Quality Criteria. The dissolved oxygen criterion was stated as "a minimum of five mg/L at any time."

Matters pertaining to the environment were established under the jurisdiction of the Department of the Environment on April 1, 1971. "Alberta Surface Water Quality Objectives" were published in January 1977. The numerical levels of the objectives were similar to the "Surface Water Quality Criteria, Province of Alberta" published in 1970. Although the objectives are not regulations as provided for under Section 2(1), where

"2(1) The Minister may make regulations

- (a) prescribing water contaminants and the maximum permissible concentration in surface water of any water contaminant either generally or with respect to any part of Alberta or any watercourse specified in the regulations;"

it was considered prudent to duplicate the numerical levels for potential future consideration of Section 2(3) of the Clean Water Act.

"2(3) Regulations made under subsection (1) shall not prescribe a permissible concentration in water of any water contaminant in excess of the permissible concentration prescribed by the Provincial Board of Health regulations for that water contaminant for the same part of Alberta or the same watercourse."

In acknowledgement of the earlier work developed by the PPWB, "Alberta, in association with Saskatchewan and Manitoba, has established minimum water quality guidelines which would allow the most sensitive use. By doing so, all other demands involving lesser quality or demands more tolerant to wider variation would also be satisfied."

Comparison of background water quality conditions with the "Alberta Surface Water Quality Objectives" provides a basis for determining the capability of a receiving water course to assimilate contaminants which originate from municipal and industrial point sources and from non-point sources. The objectives also provide a basis for the assessment of ambient water quality.

The "Alberta Surface Water Quality Objectives" for dissolved oxygen is "a minimum of five mg/L at any time."

5. APPLICATION OF THE "ANY TIME" ASPECT

Application of the "any time" aspect for the dissolved oxygen objective is predicated on the following:

- 5.1 The physiological responses of fish to hypoxia (low oxygen availability) are rapid; in trout, they consist of circulatory and ventilatory changes within a few seconds of the onset of hypoxia.
- 5.2 Any reduction in ambient oxygen to 50% saturation would severely limit energy expenditures for migrating or maximum feeding. Reductions of 30% and 43% of maximal swimming speed in rainbow trout resulted when oxygen levels fell to 50% of saturation at 23°C and 8 to 10°C.
- 5.3 High oxygen levels encourage growth rates in experimental fish. A 27-day weight gain for juvenile coho salmon at 20°C was as follows:
 - 56% at 4 mg/L
 - 68% at 5 mg/L
 - 88% at 6 mg/L
 - 92% at 8 mg/L

Food conversion efficiency is reduced at oxygen concentrations below a constant level of 4.0 mg/L.

- 5.4 There are a number of indications that fish can acclimate to some degree to lowered oxygen levels.

However, there is a scarcity of field data to show that the ability to acclimate to low oxygen markedly improves the survival chances of fish populations. Any such ability to adapt to low oxygen should be useful to some

degree, especially if the transition to a low oxygen regime is slow enough to enable acclimation to occur without physiological stress. However, the mechanism would be of little help to fish suddenly encountering low-oxygen water. Acclimation ability can be considered as a built-in safety factor for some species encountering low-oxygen conditions. There is insufficient evidence to warrant modification of oxygen criteria to include the acclimatory ability of fish.

- 5.5 Areas polluted with industrial waste, sewage, and other contaminants frequently have both low oxygen and toxicity problems. Often a number of different wastes are discharged into a body of water from various sources. The effects of these discharges can be additive. Markedly increased toxicity of ammonia solutions, salts of zinc, lead, and copper, and a mixture of monohydric phenols was evident in rainbow trout when oxygen levels fell below 60% saturation at 17.5°C. Toxicant delivery to the gills and the rate of toxicant uptake were enhanced by the increased respiratory flow necessary to counteract hypoxic conditions. Presumably, high water temperatures, hyper-activity, or some other metabolism-stimulating condition elevating respiratory activity would produce a similar result.

- 5.6 Although, the 1986 US EPA cold water criteria for dissolved oxygen stipulates a 30-day mean value of 6.5 mg/L, a 7-day mean minimum value of 5 mg/L and a 1-day minimum of 4 mg/L, a further qualification is cited:

"All minima should be considered as instantaneous to be achieved at all times."

"Absolutely no anthropogenic dissolved oxygen depression in the potentially lethal area below the 1-day minima should be allowed unless special care is taken to ascertain the tolerance of resident species to low dissolved oxygen."

The previous EPA cold water criterion for dissolved oxygen was a minimum of 5 mg/L (usually applied as a 7Q10) which is similar to the current criterion minimum.

- 5.7 The significance of conditions which fail to meet the recommended dissolved oxygen criteria depends largely upon five factors: (1) the duration of the event; (2) the magnitude of the dissolved oxygen depression; (3) the

frequency of recurrence; (4) the proportional area of the site failing to meet the criteria; and (5) the biological significance of the site where the event occurs. Evaluation of an event's significance must be largely case- and site-specific. Common sense would suggest that the magnitude of the depression would be the single most important factor in general.

A logical extension of these considerations is that the event must be considered in the context of the level of resolution of the monitoring or modelling effort. Evaluating the extent, duration, and magnitude of an event must be a function of the spatial and temporal frequency of the data. Thus, a single deviation below the criterion takes on considerably less significance where continuous monitoring occurs than where sampling comprises once-a-week grab samples. This is so because based on continuous monitoring the event is probably small, but with the much less frequent sampling, the event is not probably small and can be considerably worse than indicated by the sample. The frequency of recurrence is of considerable interest for modelling dissolved oxygen concentrations because the return period, or period between recurrences, is a primary modelling consideration contingent upon probabilities of receiving water volumes, waste loads, temperatures, etc.

- 5.8 The Canadian Water Quality Guidelines (1987) for fisheries protection of cold water early life stages and other life stages are 9.5 mg/L and 6.5 mg/L, respectively (water column measurement).
- 5.9 As an Alberta objective, the existing numerical limit of 5 mg/L for dissolved oxygen is a minimum concentration which is not to be depressed at any time. Low levels resulting from naturally occurring conditions are exceptions. The limit refers to concentrations measured in a single sample.

Averaging periods and frequency of exceedances of the numerical limit are not included.

6. DISSOLVED OXYGEN OBJECTIVES IN OTHER JURISDICTIONS

Numerical levels for dissolved oxygen objectives in other provincial and federal jurisdictions are listed in Table 1.

JURISDICTION	OBJECTIVE																																			
British Columbia (1986)	Basin-specific numerical levels: (i) Multi-tiered depending upon the presence and state of fish eggs: 7.75 mg/L 8.0 mg/L 11.2 mg/L (ii) Lakes: Minimum long-term objective of 5 mg/L near the lake bottom. (iii) 7.25 mg/L minimum (Peace River mainstream).																																			
Alberta (1977)	A minimum of 5 mg/L at any time.																																			
Saskatchewan (1988)	(i) Warm water biota: Early life stages 6.0 mg/L Other life stages 5.0 mg/L (ii) Cold water biota: Early life stages 9.5 mg/L Other life stages 6.5 mg/L																																			
Manitoba (1988)	Class 2A: 60% Saturation (instantaneous minimum). Class 2B: 47% Saturation (instantaneous minimum).																																			
Ontario (1984)	<table border="1"> <thead> <tr> <th>Temp. °C</th><th>Cold Water Biota %sat.</th><th>mg/L</th><th>Warm Water Biota %sat.</th><th>mg/L</th></tr> </thead> <tbody> <tr><td>0</td><td>54</td><td>8</td><td>47</td><td>7</td></tr> <tr><td>5</td><td>54</td><td>7</td><td>47</td><td>6</td></tr> <tr><td>10</td><td>54</td><td>6</td><td>47</td><td>5</td></tr> <tr><td>15</td><td>54</td><td>6</td><td>47</td><td>5</td></tr> <tr><td>20</td><td>57</td><td>5</td><td>47</td><td>4</td></tr> <tr><td>25</td><td>63</td><td>5</td><td>48</td><td>4</td></tr> </tbody> </table>	Temp. °C	Cold Water Biota %sat.	mg/L	Warm Water Biota %sat.	mg/L	0	54	8	47	7	5	54	7	47	6	10	54	6	47	5	15	54	6	47	5	20	57	5	47	4	25	63	5	48	4
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Continued . . .

Table 1. Concluded.

JURISDICTION	OBJECTIVE
Environment Canada (1987)	(i) Warm water biota:
	Early life stages 6 mg/L
	Other life stages 5 mg/L
	(ii) Cold water biota:
	Early life stages 9.5 mg/L(6.5)*
	Other life stages 6.5 mg/L

*Interstitial water of the gravel.

7. REFERENCES

National Research Council Canada No. 14100, Davis J.C., Waterborne Dissolved Oxygen Requirements and Criteria with Particular Emphasis on the Canadian Environment, Report No. 13, 1975.

United States Environmental Protection Agency (US EPA), Quality Criteria for Water 1986.

8. ANNEX A: TRANSPARENCIES USED FOR PRESENTATION

(Pages 19 to 25)

DISSOLVED OXYGEN OBJECTIVES IN ALBERTA
(HISTORICAL PERSPECTIVE) AND OTHER JURISDICTIONS

DISSOLVED OXYGEN OBJECTIVES WORKSHOP

CALIFORNIA
1963

IN THE SECOND EDITION OF THE WATER QUALITY CRITERIA, AUTHORED BY MCKEE AND WOLF (1963), FOR THE CALIFORNIA STATE WATER RESOURCES CONTROL BOARD,

"UNDER AVERAGE STREAM CONDITIONS, 3.0 mg/L OF DISSOLVED OXYGEN, OR LESS, SHOULD BE REGARDED AS HAZARDOUS OR LETHAL, AND THAT TO MAINTAIN VARIED FISH FAUNA IN GOOD CONDITION THE DISSOLVED OXYGEN CONCENTRATION SHOULD REMAIN AT 5.0 mg/L OR HIGHER".

PRAIRIE PROVINCES WATER BOARD (PPWB)
MARCH 1973

" ADOPTION OF WATER QUALITY OBJECTIVES WHICH HAD BEEN DEVELOPED JOINTLY BY THE PROVINCES OF ALBERTA, SASKATCHEWAN, AND MANITOBA. THE OBJECTIVES WERE PUBLISHED WITH THE UNDERSTANDING THAT THEY MAY BE AMENDED FROM TIME TO TIME BY MUTUAL AGREEMENT. WITH RESPECT TO DISSOLVED OXYGEN, THE WATER QUALITY TASK FORCE SIMPLIFIED THE CALIFORNIA CRITERIA IN TERMS OF RECOMMENDING "A MINIMUM OF 5 mg/L AT ANY TIME".

ALBERTA1969"SUMMARY SURFACE WATER QUALITY CRITERIA - PROVINCE OF ALBERTA"JANUARY 28, 1970

THE PROVINCIAL BOARD OF HEALTH REGULATIONS RESPECTING THE DISPOSAL OF WASTE WATER AND THE CONTROL OF WATER POLLUTION (DIVISION 39) WERE ADOPTED. THESE REGULATIONS PROVIDED THE PROVINCIAL BOARD OF HEALTH WITH CONTROL OF INSECTICIDES APPLIED TO WATER AND THE MECHANISM FOR THE ESTABLISHMENT OF THE WATER QUALITY CRITERIA.

AUGUST 1970

"SURFACE WATER QUALITY CRITERIA, PROVINCE OF ALBERTA" WAS PREPARED BY THE WATER POLLUTION CONTROL SECTION, DIVISION OF ENVIRONMENTAL HEALTH. THE DISSOLVED OXYGEN CRITERIA WAS STATED AS "A MINIMUM OF FIVE mg/L AT ANY TIME."

APRIL 1, 1971

MATTERS PERTAINING TO THE ENVIRONMENT WERE ESTABLISHED UNDER THE JURISDICTION OF THE DEPARTMENT OF THE ENVIRONMENT.

JANUARY 1977

"ALBERTA SURFACE WATER QUALITY OBJECTIVES". THE NUMERICAL LEVELS OF THE OBJECTIVES WERE SIMILAR TO THE LEVELS PUBLISHED IN 1970.

USE

- COMPARISON OF BACKGROUND WATER QUALITY CONDITIONS WITH THE OBJECTIVE PROVIDES A BASIS FOR DETERMINING THE CAPABILITY OF A RECEIVING WATER COURSE TO ASSIMILATE CONTAMINANTS.
- BASIS FOR THE ASSESSMENT OF AMBIENT WATER QUALITY.

APPLICATION

- AS AN ALBERTA OBJECTIVE, THE EXISTING NUMERICAL LIMIT OF 5 mg/L FOR DISSOLVED OXYGEN IS A MINIMUM CONCENTRATION WHICH IS NOT TO BE DEPRESSED AT ANY TIME.
- THE LIMIT REFERS TO CONCENTRATIONS MEASURED IN A SINGLE SAMPLE.
- AVERAGING PERIODS AND FREQUENCY OF EXCEEDANCES OF THE NUMERICAL LIMIT ARE NOT INCLUDED.
- LOW LEVELS RESULTING FROM NATURALLY OCCURRING CONDITIONS ARE EXCEPTIONS.

SIGNIFICANCE OF CONDITIONS REGARDING COMPLIANCE

THE SIGNIFICANCE OF CONDITIONS WHICH FAIL TO MEET THE RECOMMENDED DISSOLVED OXYGEN CRITERIA DEPEND LARGELY UPON FIVE FACTORS:

- DURATION OF THE EVENT;
- FREQUENCY OF RECURRENCE;
- MAGNITUDE OF THE DISSOLVED OXYGEN DEPRESSION;
- PROPORTIONAL AREA OF THE SITE FAILING TO MEET THE OBJECTIVE;
- BIOLOGICAL SIGNIFICANCE OF THE SITE WHERE THE EVENT OCCURS.

EVALUATION OF AN EVENT'S SIGNIFICANCE MUST BE LARGELY CASE- AND SITE-SPECIFIC.

COMMON SENSE WOULD DICTATE THAT THE MAGNITUDE OF THE DEPRESSION WOULD BE THE SINGLE MOST IMPORTANT FACTOR.

FISHERIES PHYSIOLOGICAL RESPONSE

- CIRCULATORY AND VENTILATORY CHANGES
- MAXIMAL SWIMMING SPEED
- GROWTH RATE
- FOOD CONVERSION EFFICIENCY
- ACCLIMATION TO LOWERED OXYGEN LEVELS IF TRANSITION IS SLOW - NOT SUDDEN
- INSUFFICIENT EVIDENCE TO WARRANT MODIFICATION OF OXYGEN OBJECTIVE TO INCLUDE ACCLIMATORY ABILITY OF FISH.
- ADDITIVE EFFECTS OF TOXIC WASTES AND LOW OXYGEN LEVELS. TOXICANT DELIVERY TO THE GILLS AND THE RATE OF TOXICANT UPTAKE ENHANCED BY THE INCREASED RESPIRATORY FLOW NECESSARY TO COUNTERACT HYPOXIC CONDITIONS.



AMBIENT OBJECTIVES: STATUS

by

H.P. Sims
Standards Research and Development Branch
Alberta Environment

The Standards Research and Development Branch was established to develop and recommend ambient objectives or guidelines for chemicals and traditional parameters.

The Branch will deal primarily with air, water, and multimedia, but also soils and sediments.

The Branch has developed a process consisting of five distinct elements:

Priority Setting
Criteria Document
Objectives Document
Position Paper
Policy Document

The first element - Priority Setting - is a screening process to select chemicals based on environmental distribution, exposure potential, and toxicity. This activity consists of three phases (Figure 1).

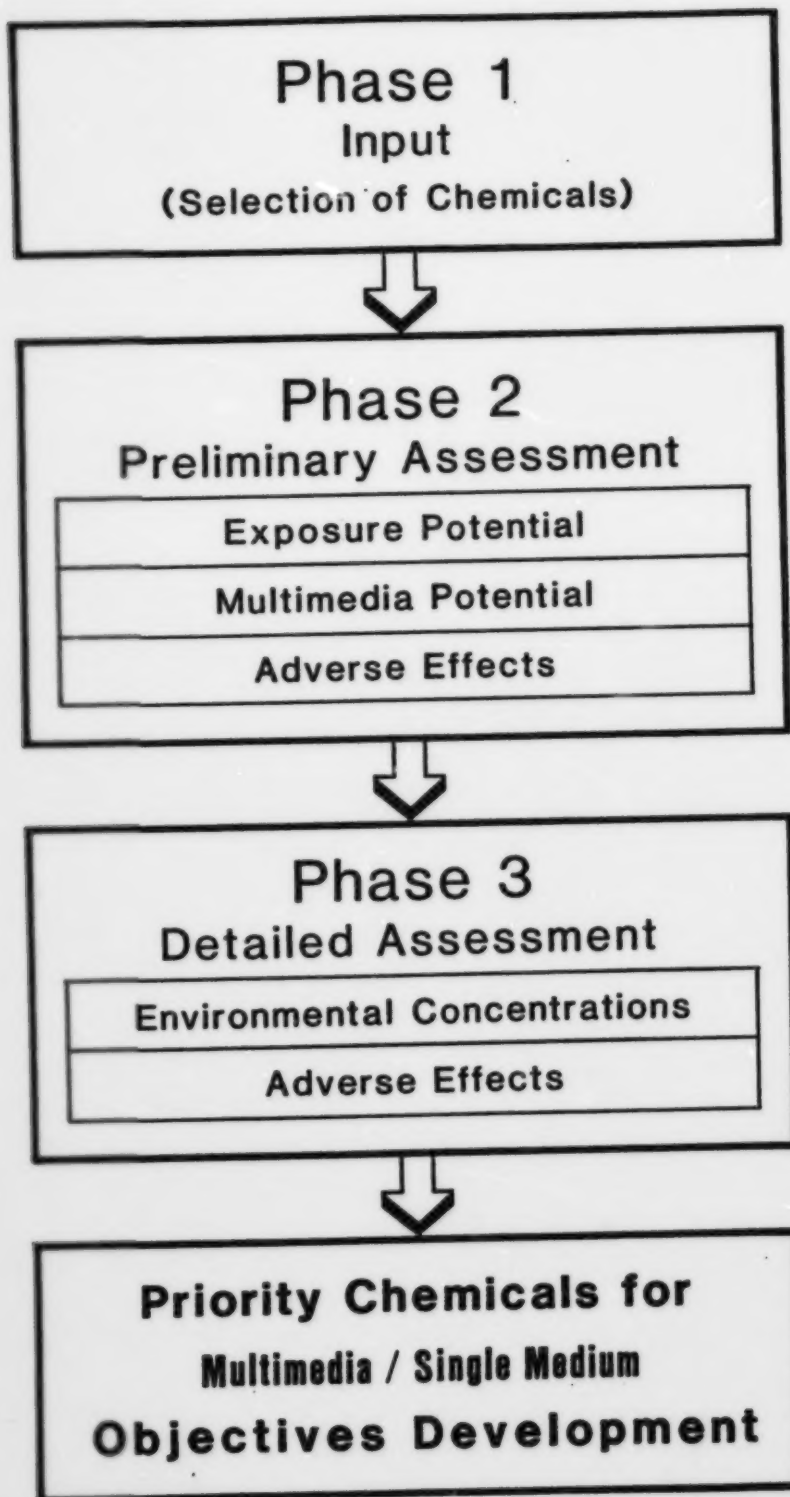
The second element is the preparation of a Criteria Document. This may involve assembling existing data (such as existing Criteria Documents) and a review of applicability to Alberta. An existing objective may be adopted as is, or modified for Alberta.

If an objective cannot be adopted, a Criteria Document will be prepared from compiled and technical information about the parameter of concern. In such cases, an interim objective may have to be recommended.

Once the Criteria Document is completed, or if an interim objective is recommended, the Standards Research and Development Branch will develop an Objectives Document. This document will reflect the criteria in terms of environmental quality objectives and protection from adverse health and environmental effects.

The proposed objective must be reviewed to determine the:

- implications of the objective;
- feasibility of implementation;
- specifics about the objective;



- monitoring details;
- QA/QC of analytical data; and
- resources and budget.

Following review of the Objectives Document, a Departmental Position Paper will be prepared.

The Position Paper may lead to Department Policy. Draft policy would include:

- conformation to Departmental Mission Statement;
- identification of most sensitive receptors (health, vegetation, animal life, etc.);
- an estimation of costs and benefits, if possible;
- presentation of the risk assessment results;
- indications that recommended levels are scientifically and technically defensible.

The Standards Research and Development Branch will utilize external technical and scientific reviews and workshops as key tools to ensure that objectives will be scientifically defensible and will withstand critique.

Examples are the Dissolved Oxygen Workshop, and the Risk Assessment Workshop in February.

This is a proposed process for objective setting and is presently being prepared for Department approval.



DISSOLVED OXYGEN MONITORING IN ALBERTA RIVERS

by
D.O. Trew
Environmental Quality Monitoring Branch
Alberta Environment

1. BACKGROUND

The historical record of dissolved oxygen [DO] measurements in Alberta can be traced back to the 1940s through the published work of Rawson and R.B. Miller. The original studies were of a descriptive nature and focussed on the basic limnological characteristics of Alberta's lakes, rivers, and streams.

The focus of [DO] studies shifted to applied sanitary engineering in the 1950s due to the gross pollution of the North Saskatchewan River and other rivers by unregulated municipal/industrial discharges. Extensive data bases relating BOD loadings to river [DO] were assembled by the Division of Sanitary Engineering, Department of Health, and by various graduate students at the University of Alberta.

During the 1960s, several long-term monitoring sites were established by the provincial government. Monthly grab samples at key locations upstream and downstream from major urban areas were taken in the late 1960s and early 1970s. A number of continuous, automatic monitoring stations were also implemented which provided a detailed record of seasonal/ diurnal fluctuations downstream from major BOD sources.

In the past two decades the scope of river [DO] investigations has expanded considerably with detailed synoptic survey data bases now available for all the major river basins of the province. These surveys have been conducted to aid in river management decisions related to a variety of issues (municipal and industrial pollution control, river impoundment, winter oxygen depletion, etc.).

All of the early observations were made using the Winkler method. Electronic meters using membrane electrodes have been used regularly since the installation of the robot monitors in the late 1960s. However, the use of electronic meters entails intensive quality control and calibration, and the Winkler method remains the method of choice in many applications. This substantial provincial data base is stored on NAQUADAT.

2. INFORMATION

A selection of diagrams has been assembled to illustrate the high degree of specificity of [DO] variation in individual Alberta rivers. These variations can be extensive over space and time.

The first diagram (Figure 1) is a map of Alberta which simply illustrates the location of long-term monitoring sites for the 13 fixed sites and the remaining, operational robot monitors (#1, 3, and 4). The robot network is being revised.

The small rivers with sources in the parkland or boreal mixed-wood forest biomes (Battle and Beaver) undergo pronounced seasonal variation in [DO]. This is illustrated by the long-term graph of [DO] (Figure 2) in the Battle River at Unwin, Saskatchewan (the PPWB site). Dissolved oxygen is the highest (in terms of concentration) during spring and fall when water temperatures are low. Summer concentrations are lower due to high temperatures and biological activity, and winter concentrations approach zero due to high demand and negligible replenishment.

The rapid rate at which [DO] can decline after initial ice formation in early winter is illustrated in Figure 3. The data are taken from the upper Beaver and Sand rivers from November and December 1984.

Variation over even shorter time spans is illustrated by Figure 4, which shows the profound diurnal [DO] cycling in a eutrophic river system (i.e., the Bow River in summer 1989). Such diurnal changes can be seen over the spatial scale on the next diagram (Figure 5). This plot illustrates the classic [DO] sag at night as one proceeds downstream from a major BOD source (Bow River, summer 1962).

Spatial trends in [DO] depletion in a pristine system are illustrated in Figure 6. In the absence of re-aeration under complete ice cover, the waters of the upper Beaver, Sand, and lower Beaver rivers undergo progressive oxygen depletion in a downstream direction, illustrating that even in the absence of a significant BOD source, conditions can vary between reaches and over short distances.

In more intensively managed basins, spatial [DO] depletion can change significantly over time. This is illustrated in Figure 7, which shows the improvements in winter [DO] in the NSR between the 1950s and 1980s as a result of the implementation of fundamental sewage treatment for the City of Edmonton, and increased winter flows due to the construction of the Bighorn and Brazeau dams. Similarly, Figures 8 and 9 demonstrate the positive effect of the Dickson Dam on winter [DO] in the Red Deer River.

In summary, these data illustrate that our major river basins display unique spatial and temporal variations in [DO]. It is apparent that, due to these characteristics, no single value can be set as an objective, and that the individual conditions of pre-defined 'water quality' reaches should be considered in the objective-setting process.



Figure 1. Long-term river and lake monitoring sites.

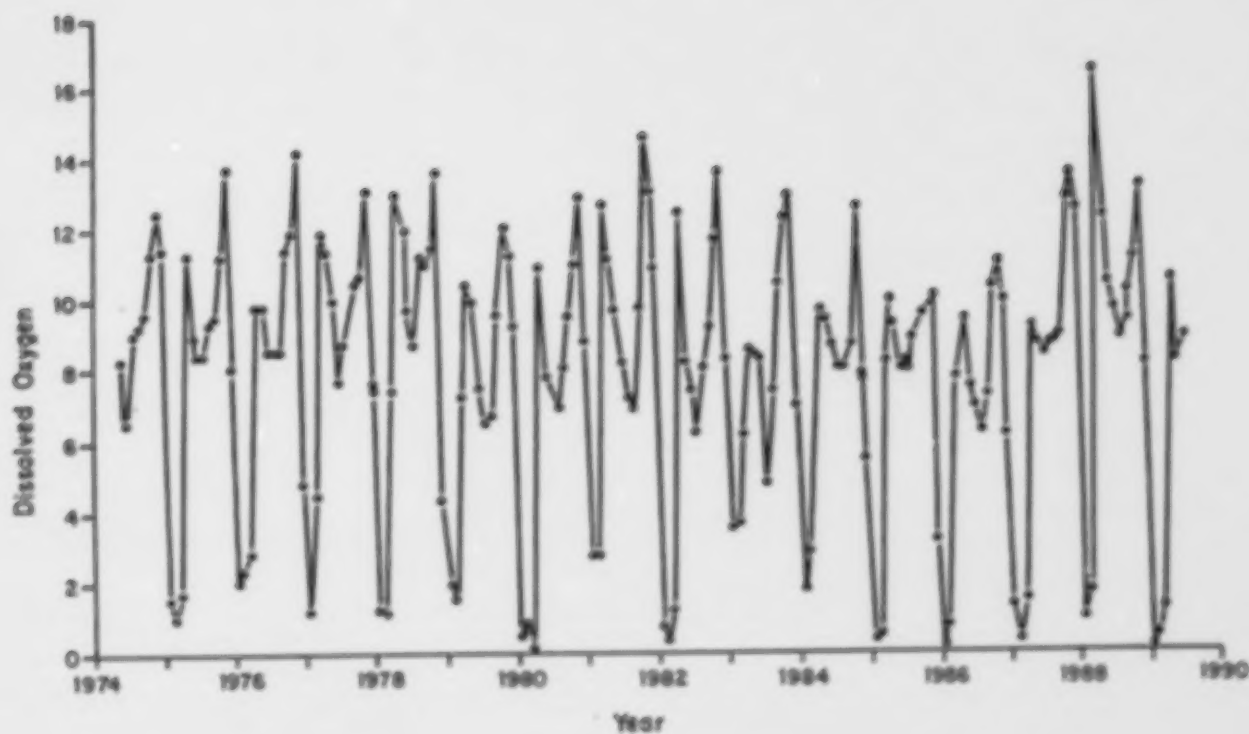


Figure 2. Dissolved oxygen - Battle River at Unwin (mg/L).

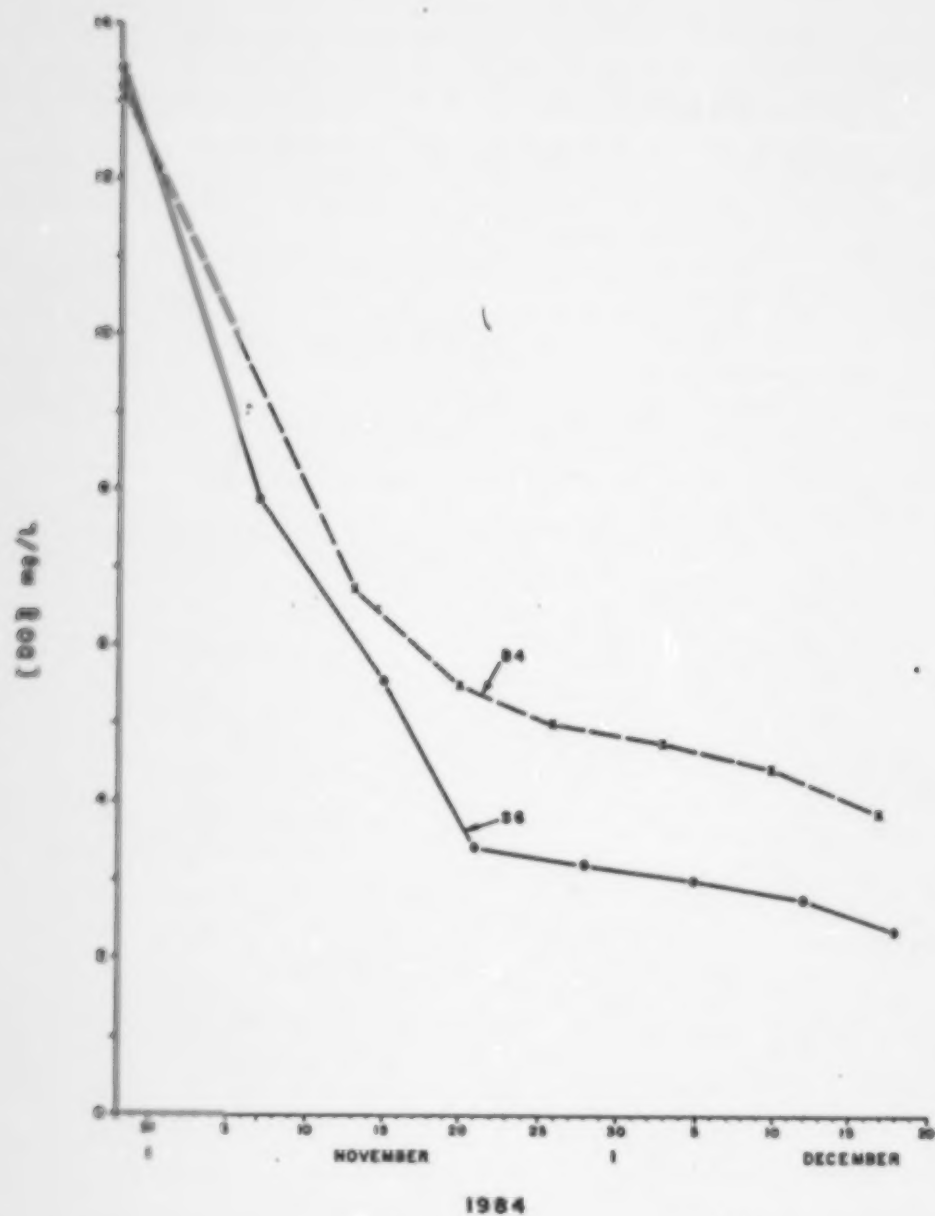


Figure 3. Temporal [DO] depletion recorded at B4 and S6 in late 1984.

DISSOLVED OXYGEN VALUES SUMMER 1989

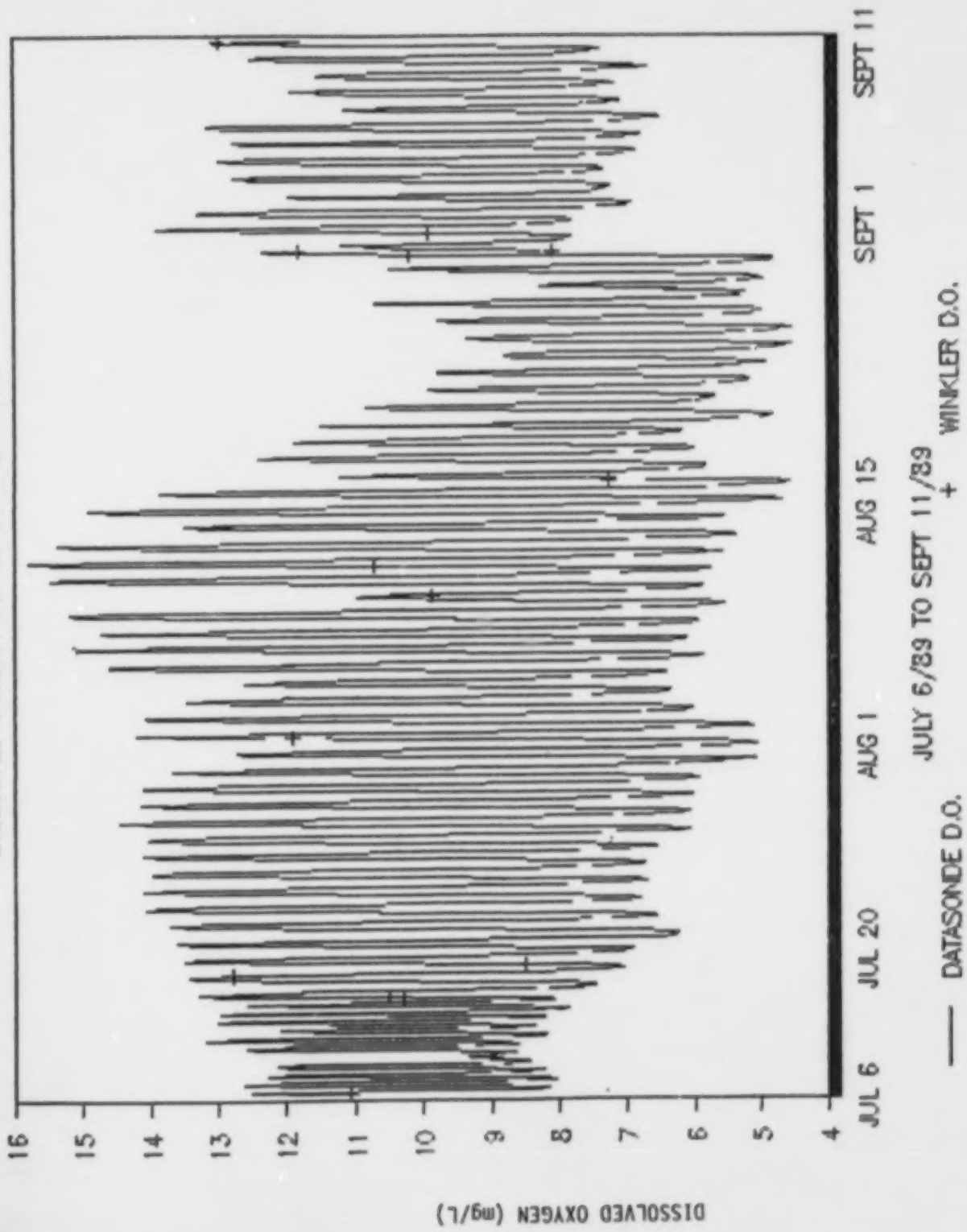


Figure 4. Bow River above Fish Creek treatment plant.

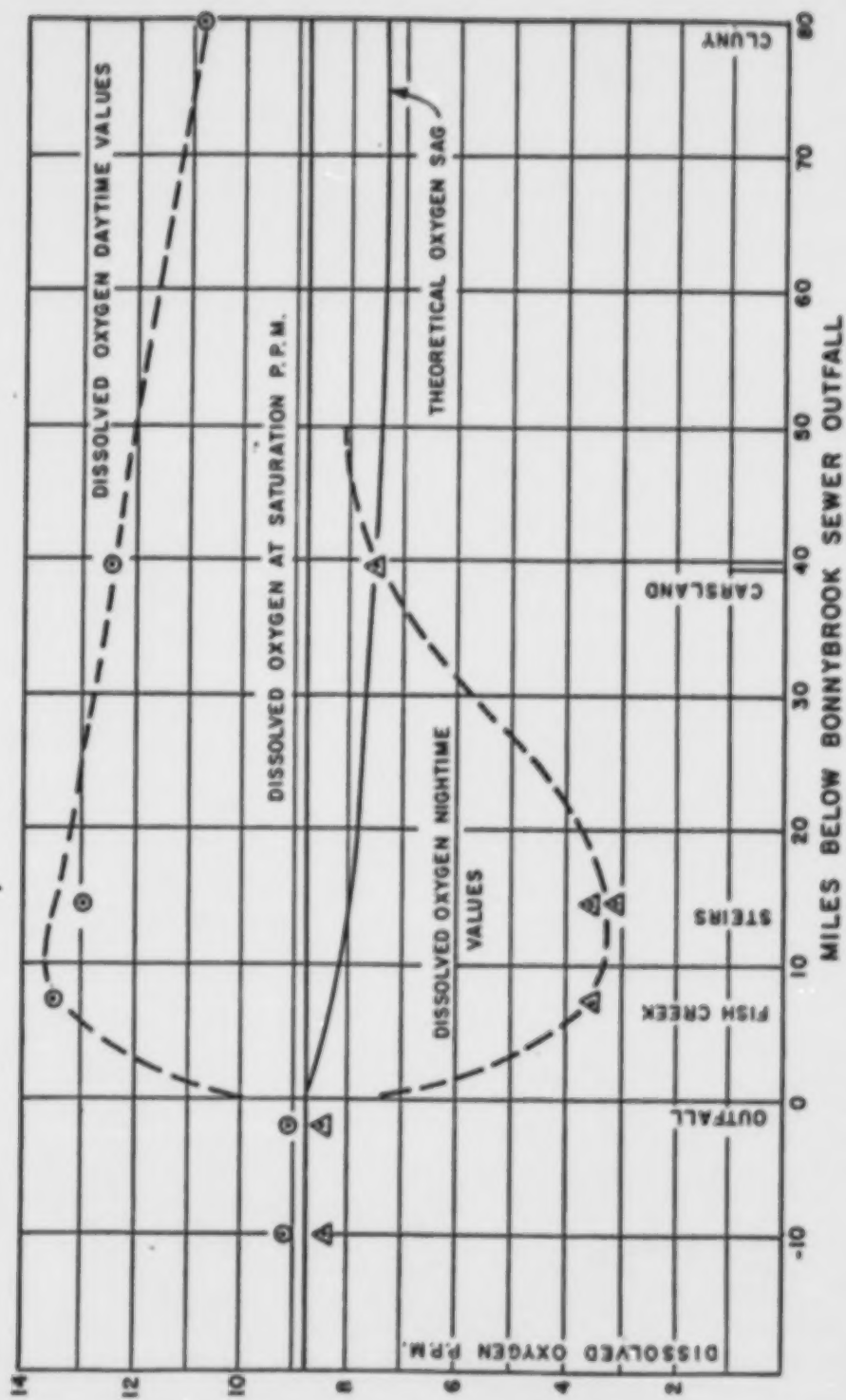


Figure 5. Dissolved oxygen in the Bow River above and below Calgary - a comparison of daytime and nighttime values, 1962.

Source: Division of Sanitary Engineering, Alberta Department of Public Health).

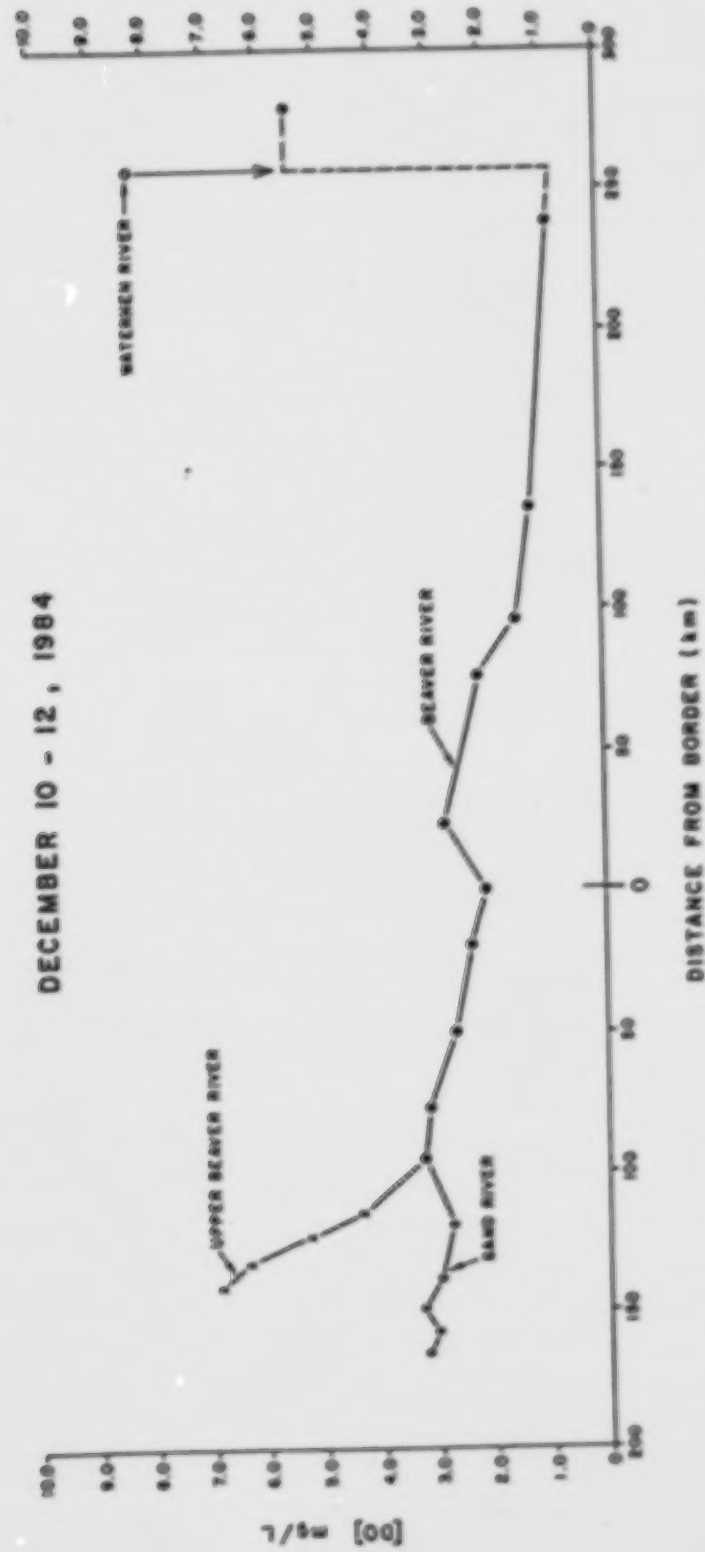


Figure 6. Longitudinal profile of [00] in the Beaver River during December 10-12, 1984.

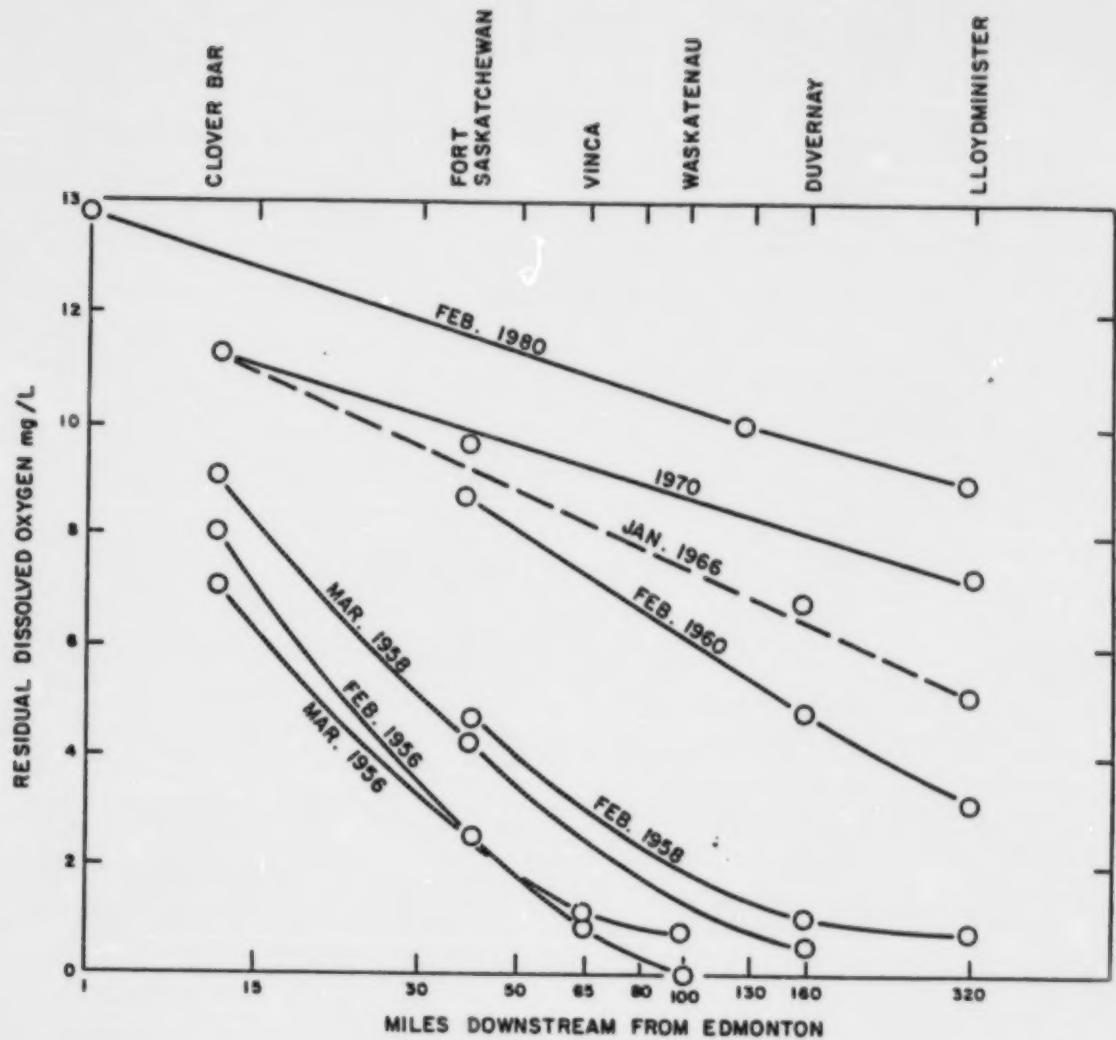


Figure 7. Residual dissolved oxygen, North Saskatchewan River.

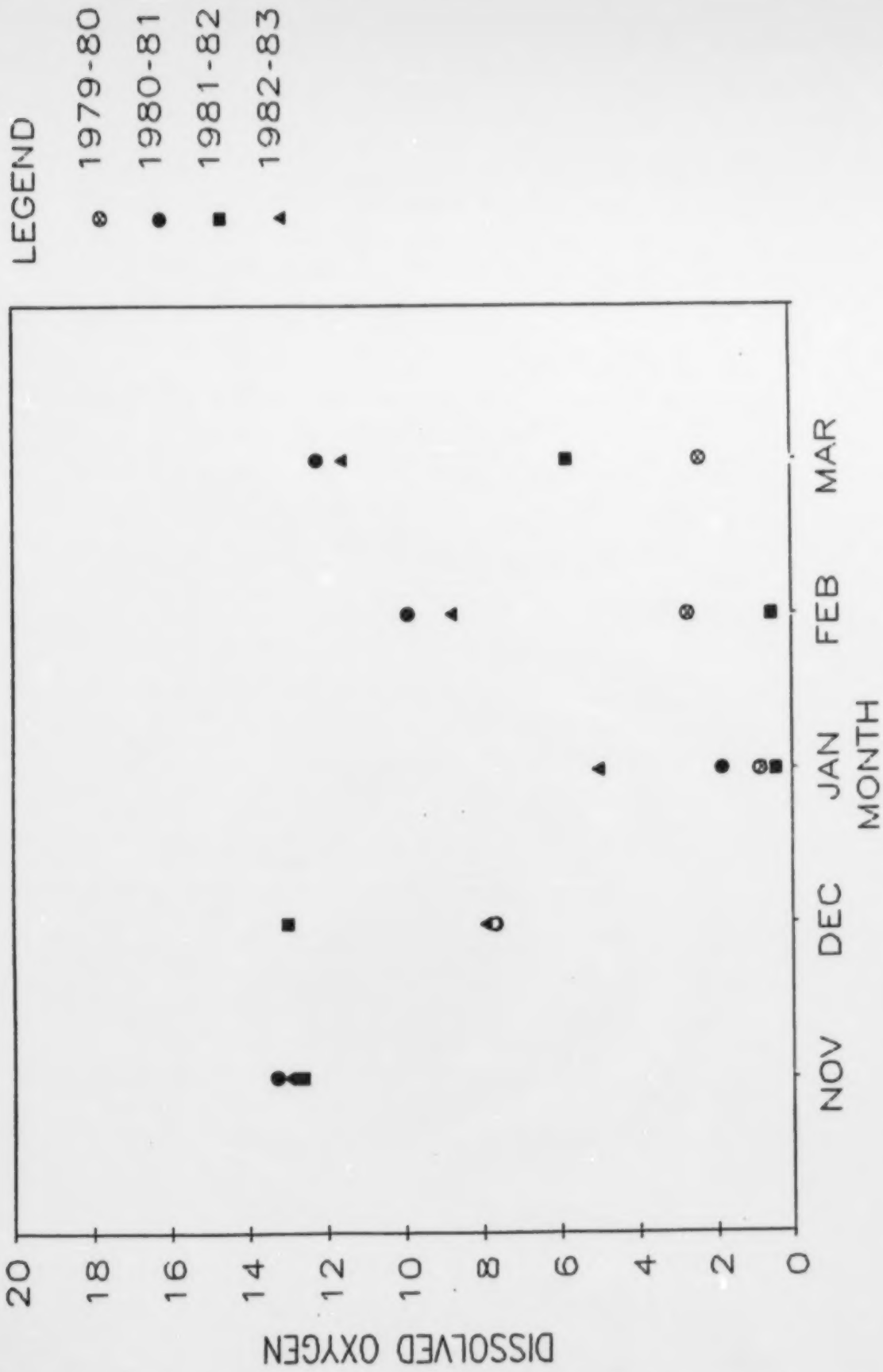


Figure 8. Red Deer River - Drumheller Pre-dam.

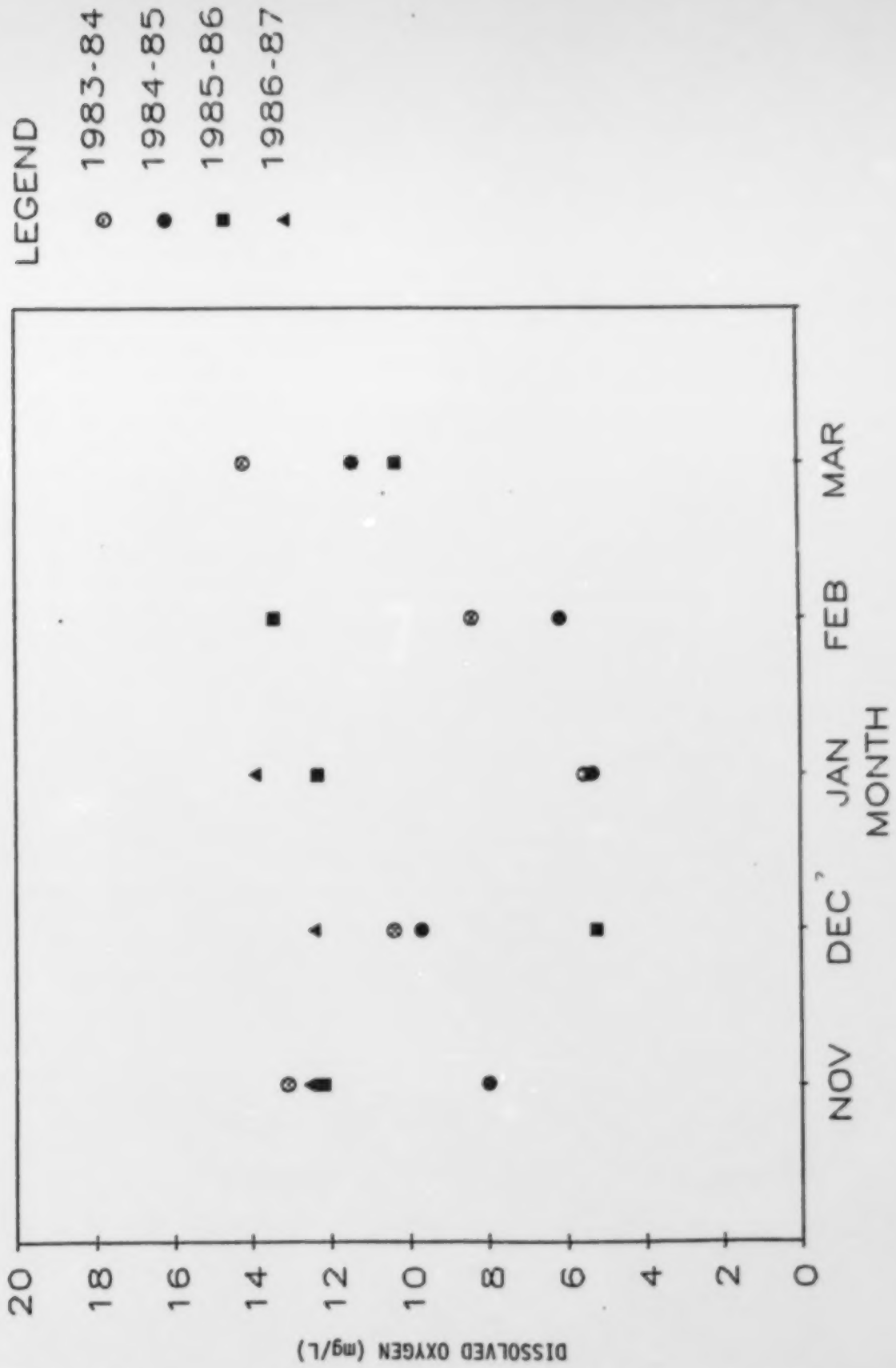
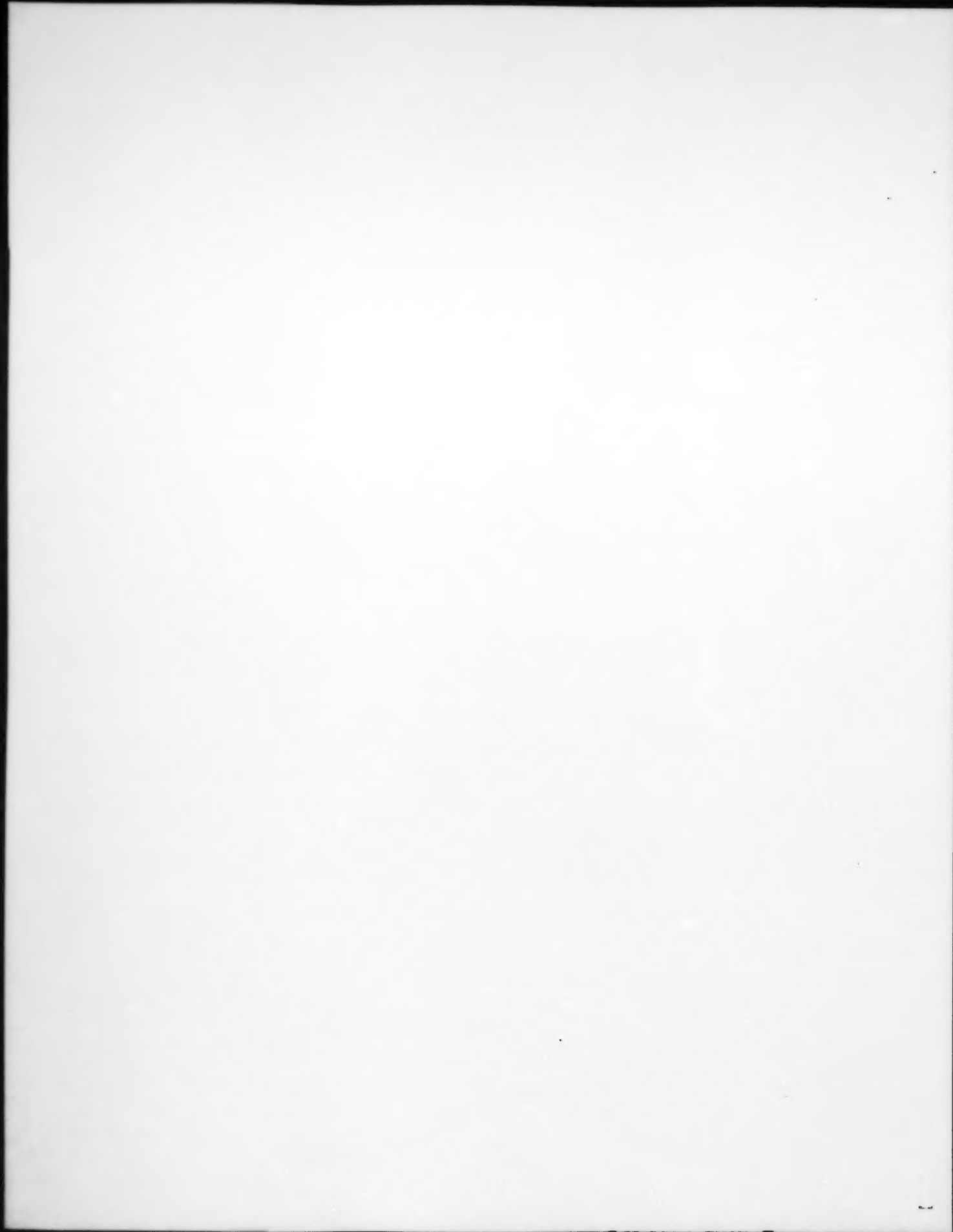


Figure 9. Red Deer River - Drumheller Post-dam.



DISSOLVED OXYGEN MONITORING IN ALBERTA LAKES

by

P. Mitchell
Environmental Quality Monitoring Branch
Alberta Environment

LAKE STUDIES IN ALBERTA

Dissolved oxygen concentration is routinely measured in all lake studies conducted by the Environmental Quality Monitoring Branch. These would include: (1) impact assessments, such as the effect of diversions into lakes to stabilize the water level, or the impact of sewage effluent on lake water quality; (2) long-term trend evaluations, such as the sampling programs that have been conducted on Baptiste, Wabamun, Ethel, and Nakamun lakes since 1980 or 1983. This would also include 20 to 25 lakes that have been sampled since 1983 in a lake water quality monitoring program conducted jointly with Alberta Recreation and Parks; and (3) baseline surveys, in which lakes are sampled monthly during the open-water season for two years.

Lake water quality studies began in the 1940s when R.B. Miller conducted surveys on many lakes to assess their suitability for fish production. These studies were generally brief and general, but they provide useful anecdotal information, including dissolved oxygen conditions on a particular day. Since then, Fish and Wildlife Division has measured dissolved oxygen concentration on many lakes, particularly those they stock.

Alberta Environment funded University of Alberta studies on about 15 lakes during 1973 to 1976, and began lake survey programs with in-house staff in 1976. At present, Alberta Environment has information on 368 lakes and reservoirs. Some of this information is minimal, but perhaps half of these water bodies have been sampled on more than one occasion and include dissolved oxygen measurements.

Present-day surveys on lakes include the measurement of dissolved oxygen concentration at 1-m intervals from the lake surface to the bottom with Hydrolab equipment calibrated on the same day. These measurements are checked with Winkler determinations at several depths. The profile is done in the deepest areas of each basin of the lake on a monthly basis during open water and once during winter, usually in February. For some studies, sampling and profiles are conducted more frequently, whereas for the provincial park lakes, such profiles are done only twice per year, in winter and summer.

MOORE LAKE

Moore Lake provides an example of a typical lake studied by Alberta Environment. It is fairly deep (24 m) and relatively unimpacted

by cottage development or agriculture. The lake has good water quality but will have mild algal blooms at times during the summer and fall. It is classified as eutrophic, but on the low end of the scale (average chlorophyll 12 $\mu\text{g/L}$).

Moore Lake thermally stratifies in summer: a light, warm layer of water develops over a cool, heavier layer. In 1980, the thermocline was evident at about 8 or 9 m deep (Figs. 1 and 2). The upper layer or epilimnion supports populations or phytoplankton which take advantage of light, warmth, and nutrients. During summer, algal cells and other organic material rain into the lower layer or hypolimnion. The oxygen demand from bacterial decomposition of this sedimenting organic matter and from the sediment-water interface results in a rapid loss of oxygen in this layer. In Moore Lake, the bottom 10 or 12 m of water was anoxic by mid-June in 1980. Most Alberta lakes that are deep enough to stratify exhibit hypolimnetic anoxia during the summer.

In the epilimnion, oxygen saturation depends on the circulation of the water by wind and algal photosynthesis. Moore Lake maintained high dissolved oxygen concentrations in this layer all summer in 1980. In some highly productive lakes, supersaturation occurs, and dissolved oxygen concentration can reach 20 mg/L. Conversely, some sheltered or unproductive lakes rarely achieve oxygen saturation in the upper layer.

Many deeper Alberta lakes mix incompletely or not at all in spring. This would occur when there is rapidly increasing air temperature and little wind in May just after ice-out, conditions that seem to occur regularly in north and central Alberta. Anoxic water near the lake bottom is maintained into the summer stratification period. Even in autumn, mixing may be incomplete, so that some lakes rarely have well-oxygenated water near the lake bottom. Occasionally, weather conditions are such that a lake which normally mixes in autumn, goes into ice cover with only partially oxygenated water. A winterkill may result, as occurred in Battle Lake in 1980.

Many Alberta lakes are shallower than Moore Lake. The shallowest relative to their fetch and size may mix continuously from the surface to the bottom all summer; examples are Wabamun and Buffalo lakes. Such lakes are well oxygenated during the open-water period. Other lakes, for example Wizard and Pine lakes and Lac La Biche, are deep enough to stratify during mid-summer or on calm days, but the thermocline is weak and subject to disruption on windy days. In these lakes, oxygen depletion occurs when the water column is stratified, but reoxygenation takes place when the lake mixes. Such weakly thermally stratified lakes tend to be quite productive because phosphorus recycling from the bottom sediments (internal loading) is enhanced.

DEGREE OF OXYGEN DEPLETION IN LAKES

The degree or extent of oxygen depletion in lakes depends primarily on the lake's productivity level--eutrophic or hyper-eutrophic

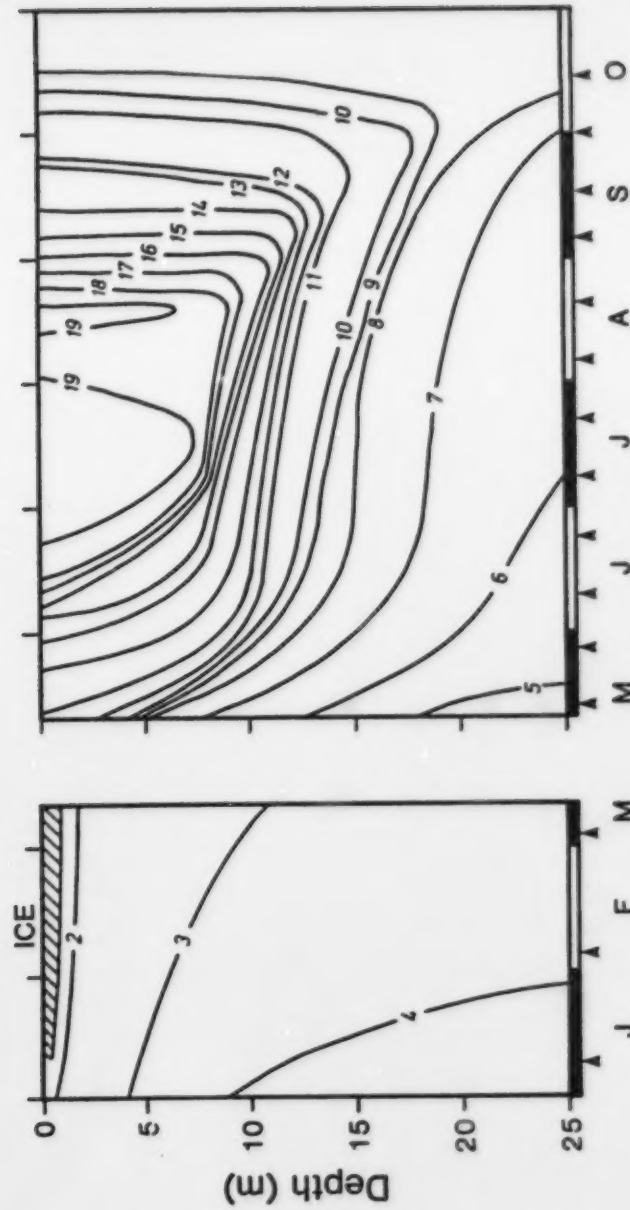


Figure 1. Temperature ($^{\circ}\text{C}$) in Moore Lake, 1980.

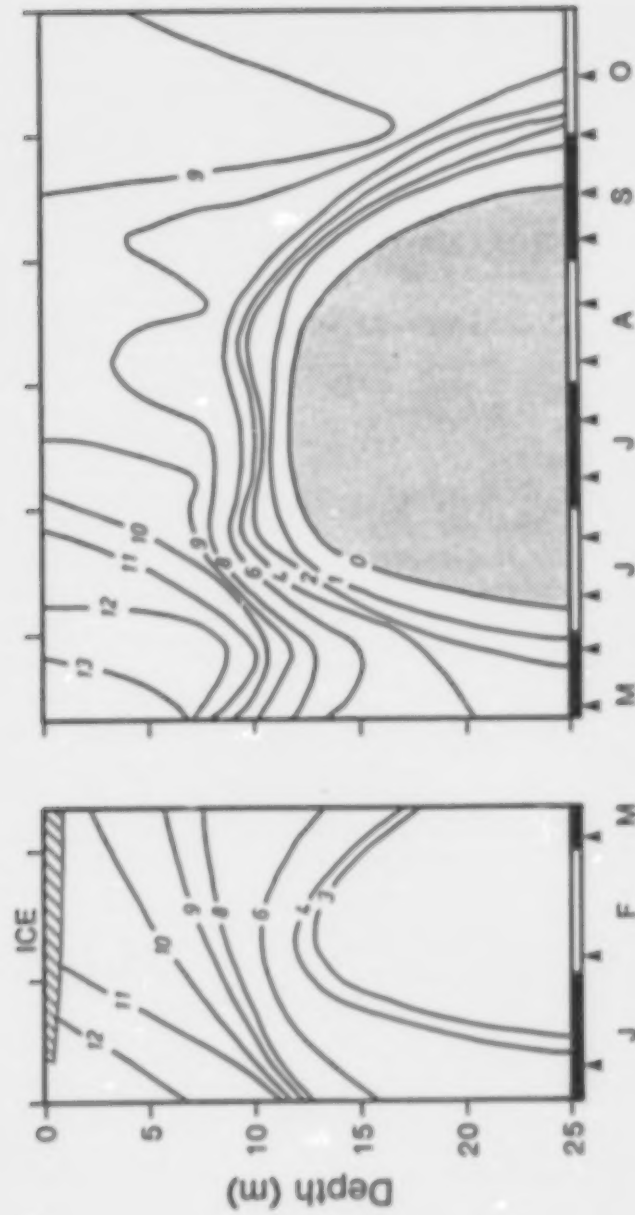


Figure 2. Dissolved oxygen concentration (mg/L) in Moore Lake, 1980.

lakes will have greater oxygen deficits than less productive lakes--and on the mean depth of the lake. In lakes that are shallow and highly productive, oxygen concentrations may range from supersaturation near the surface to anoxia at the bottom. This was observed in Field Lake, a 4-m deep lake that receives sewage effluent.

In winter, the degree of oxygen loss also depends on the amount of snow cover and on the total mass of oxygen in the lake at the onset of ice-cover. When the snow cover is thick, light transmission is reduced and photosynthetic replenishment of oxygen is reduced or nil.

Oxygen depletion rates have not been measured extensively in Alberta lakes. Winter studies conducted in 1982 to 1983 by J. Babin, a University of Alberta graduate student, indicated that the highest rates ($\text{g O}_2/\text{m}^2$ per day) occurred early in winter, and that there was a significant correlation with lake productivity. Depletion rates, for 12 lakes in central Alberta, ranged from 0.19 to 0.85 g/m^2 per day (Babin and Prepas 1985). In comparison, summer volumetric hypolimnetic oxygen deficits ranged from 0.03 to 0.27 g/m^3 per day for nine lakes in the Cold Lake area during an Alberta Environment study on water supply alternatives for heavy-oil extraction plants (Trew 1985).

GENERAL DISCUSSION AND CONCLUSIONS

Oxygen depletion is a natural characteristic of Alberta's productive lakes. Many native species of fish are adapted to survive low oxygen levels, perhaps as low as 1 mg/L in winter. In spite of this, winterkills occur regularly on some lakes. Low oxygen levels can also be a problem in summer, but fish can often move out of weed beds or shallow bays to avoid critical oxygen concentrations.

It would not be practical to set objectives for ambient dissolved oxygen concentration in our lakes, for the following reasons:

1. Oxygen levels fluctuate widely from lake to lake, over seasons and from the lake surface to the bottom.
2. Because these conditions occur naturally, they cannot be changed or improved through regulatory functions.
3. The factors that affect oxygen depletion are complex, and cause and effect relationships in lakes are rarely clear-cut or apparent.

Our highest quality lakes should be protected, and guidelines or objectives for dissolved oxygen based on survey data for individual lakes could assist in the monitoring and assessment of these lakes. Of more value, however, would be the establishment of objectives for direct indicators of water quality such as total phosphorus.

REFERENCES

- Babin, J. and E.E. Prepas. 1985. Modelling winter oxygen depletion rates in ice-covered temperate zone lakes in Canada. *Can. J. Fish. Aquat. Sci.* 42(2):239-249.
- Trew, D.O. 1985. Impact of the proposed Cold River flow reductions on the water quality of Pierce Lake, Lepine Lake, and Lac des Isles. Alberta Environment, Water Quality Control Branch.

SOME ASPECTS OF MEASURING DISSOLVED OXYGEN IN THE ATHABASCA RIVER

by

L. Noton
Environmental Quality Monitoring Branch
Alberta Environment

The purpose of the information presented here is to illustrate some of the aspects that must be considered in measuring oxygen in rivers, particularly in winter, and the implications these factors have for a water quality objective. Recent winter oxygen conditions in the Athabasca River are more fully described by Noton and Shaw (1989).

The first factor to consider is spatial variation in dissolved oxygen [DO]. Typically, concentrations decline longitudinally down a river system under winter ice cover and selection of monitoring locations must take this into account. As well, there can be variation in DO across the channel, depending on the degree of mixing of upstream tributaries and the presence of slow-flowing or quiescent backwaters. Even fairly well mixed sites with relatively simple cross-sectional geometry can have significant variation in DO across the channel, as illustrated in Figure 1. In general, measurement of [DO] should probably be done at the centre of flow (thalweg).

A second factor, of course, is the method of measuring [DO]. The azide-Winkler method is the most accurate, precise, and reliable for surface waters and is the method used in our critical work. Polarographic meters are used for many field situations and the Environmental Quality Monitoring Branch has recently started using recording meters (Hydrolab Data Sonde 2030) where a semicontinuous record of [DO] is needed. These have been deployed on the Athabasca River (Figure 2), and the instruments usually achieve the acceptance criteria of being within ± 0.5 mg/L of a corresponding Winkler measurement. However, to operate this accurately the instruments require regular and knowledgeable maintenance to the extent that the data shown in Figure 2 represent about a full-time commitment of one technician (D. Allan, pers. comm.).

The third factor to consider is temporal variation in DO. The recording meters document such variation well and Figure 2 illustrates the general decline in [DO] in the Athabasca in January, a levelling off at winter lows in February-March, and then the start of the spring increase in late March. However, even during the fairly stable winter "low" period, there is variability in [DO] as shown in the plot of hourly and daily mean [DO] in Figure 3. We have calculated various statistics for these data (Table 1) using the mean daily [DO]. Hourly measurements appear to be overly affected by instrument variability. This is evident

on the plot for the site upstream of Whitecourt where the instruments were changed on March 7 and hourly variation changed markedly. The relative variability (CV) in mean daily [DO] at both sites was fairly low (1 to 4%). During that time period, river discharge and effluent loads were fairly stable. Major changes in flow and/or effluent loads would increase the variability in the river [DO].

Temporal variation in [DO] has an obvious implication when setting [DO] objectives for rivers and when defining compliance or achievement. If 100% compliance were to be required, and if [DO] were to behave as it did upstream of Smith, it would be necessary to set a target mean about 0.6 mg/L higher than the objective, in order to have 100% compliance. For example, to achieve 6.5 mg/L at all times, a target mean of 7.1 mg/L would be required. This also assumes the target is attainable.

If some level less than 100% compliance were judged to be acceptable, the statistics in Table 1 could aid in selecting a different target. If some frequency of "failure" is considered acceptable, duration of failures can be measured on the graph, for example, a [DO] of 6.21 mg/L was failed 25% of the time, and the maximum duration of failure was 4 days. Note that the failures tend to occur in stretches - [DO] did not fluctuate randomly about the mean but tended to stay low for several days on end. Thus, it may be necessary to consider how long fish eggs, for example, can tolerate such failures.

References

- Noton, L.R. and R.D. Shaw. 1989. Winter water quality in the Athabasca River system 1988 and 1989. Prepared by Environmental Assessment, Alberta Environment. 200 pp.

Table 1. Oxygen variability from continuous recorders.

	Mean Daily [DO] - mg/L - Athabasca River 22 February to 23 March 1989	
	Upstream of Whitecourt	Upstream of Smith
Mean	9.30	6.37
n	30	30
Std. Deviation	0.11	0.28
Coeff. Variation	1%	4%
Range	0.47	1.21
Max.	9.49	7.07
90th Percentile	9.45	6.83
75th	9.35	6.49
50th (median)	9.29	6.32
25th	9.27	6.21
10th	9.15	6.09
Min.	9.02	5.86

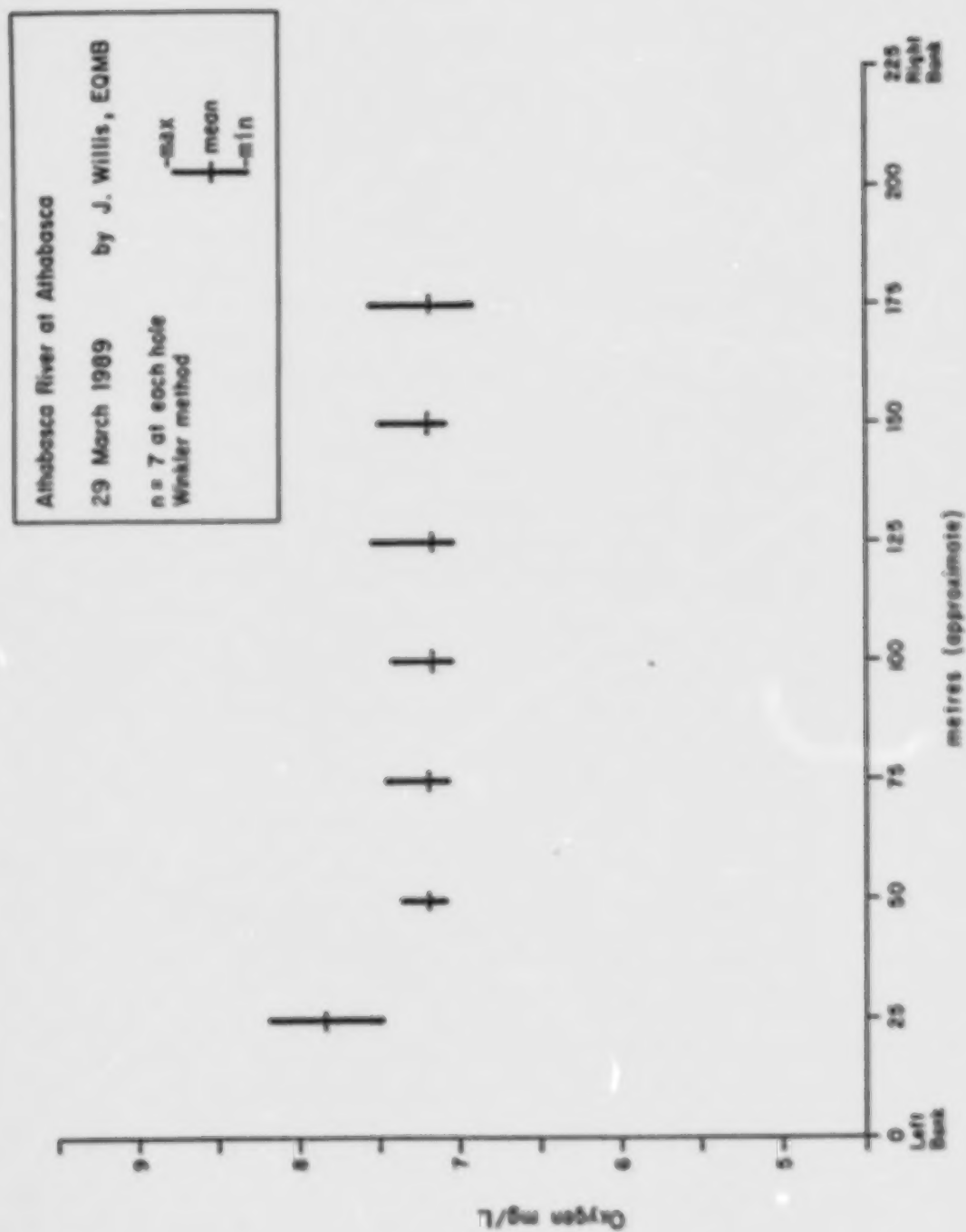


Figure 1. Cross-channel variation in oxygen.

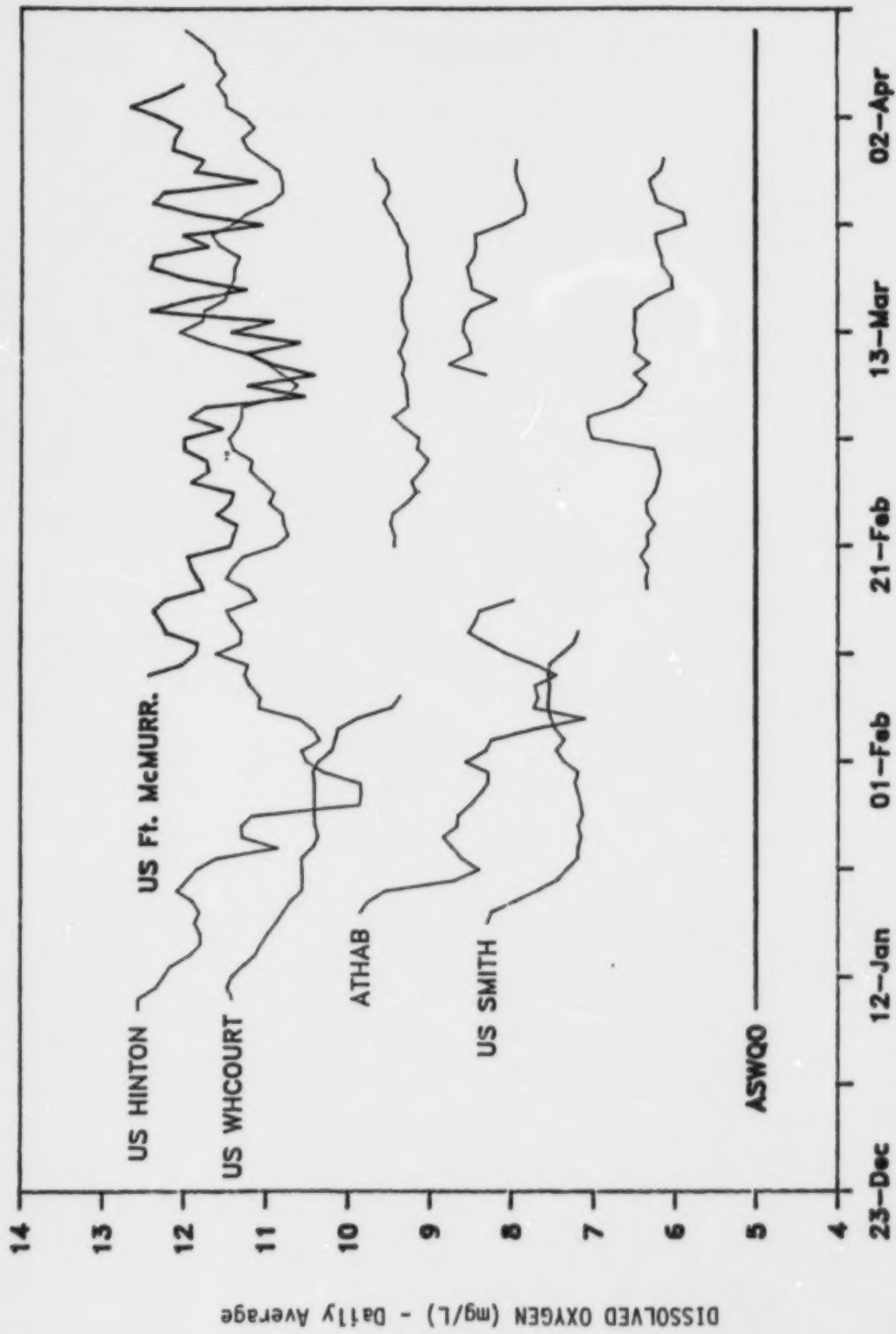


Figure 2. Winter dissolved oxygen, Athabasca River.

(Feb. 22 - Mar. 23, 1989)

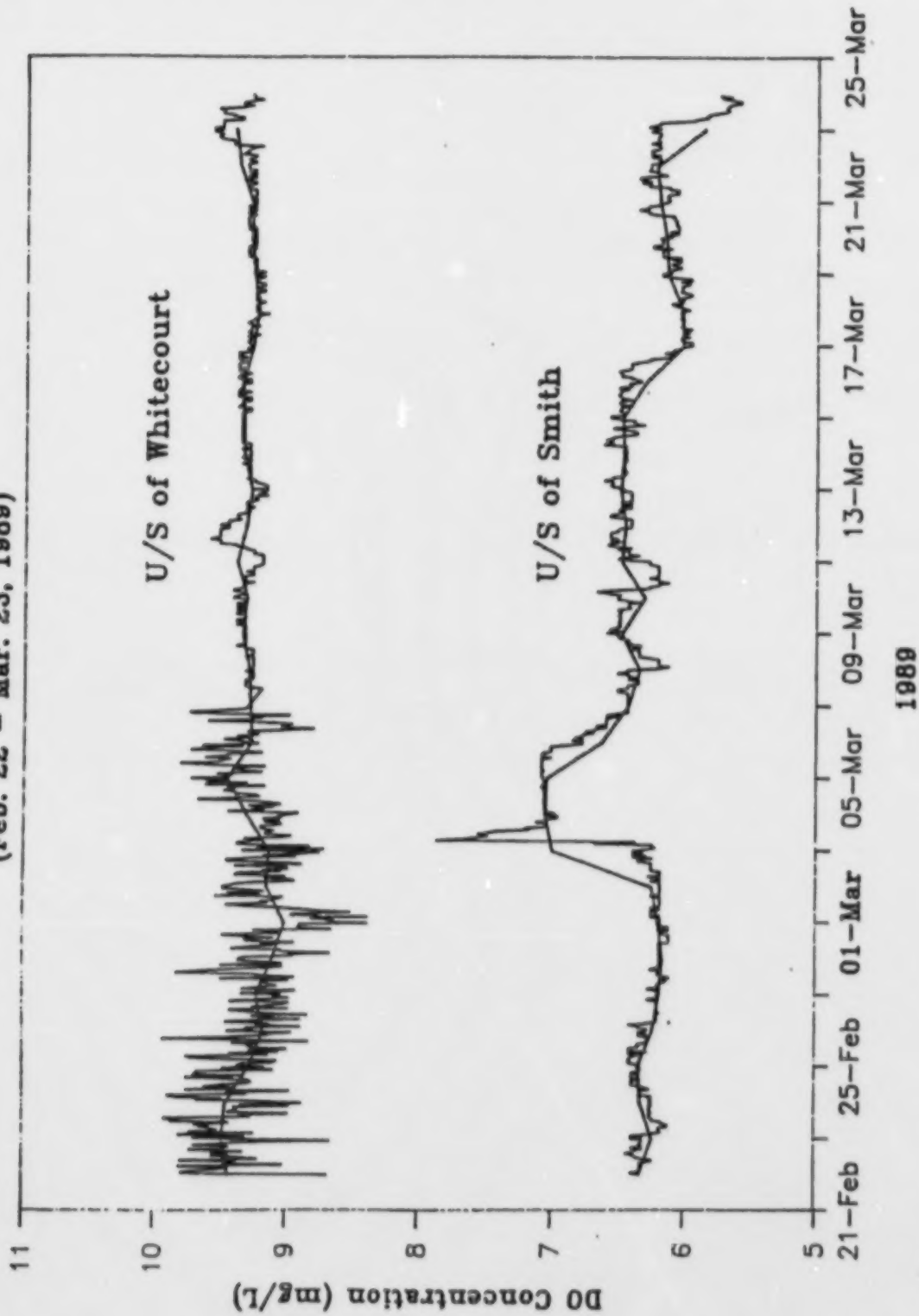


Figure 3. Hourly and daily average dissolved oxygen concentrations, Athabasca River.

DISSOLVED OXYGEN GUIDELINES - AQUATIC TOXICOLOGY

by
J. Moore
Alberta Environmental Centre

Many laboratories, including the Alberta Environmental Centre, use the following dissolved oxygen guidelines for the maintenance and use of fish:

- salmonids, 60% saturation
- nonsalmonids, 40% saturation

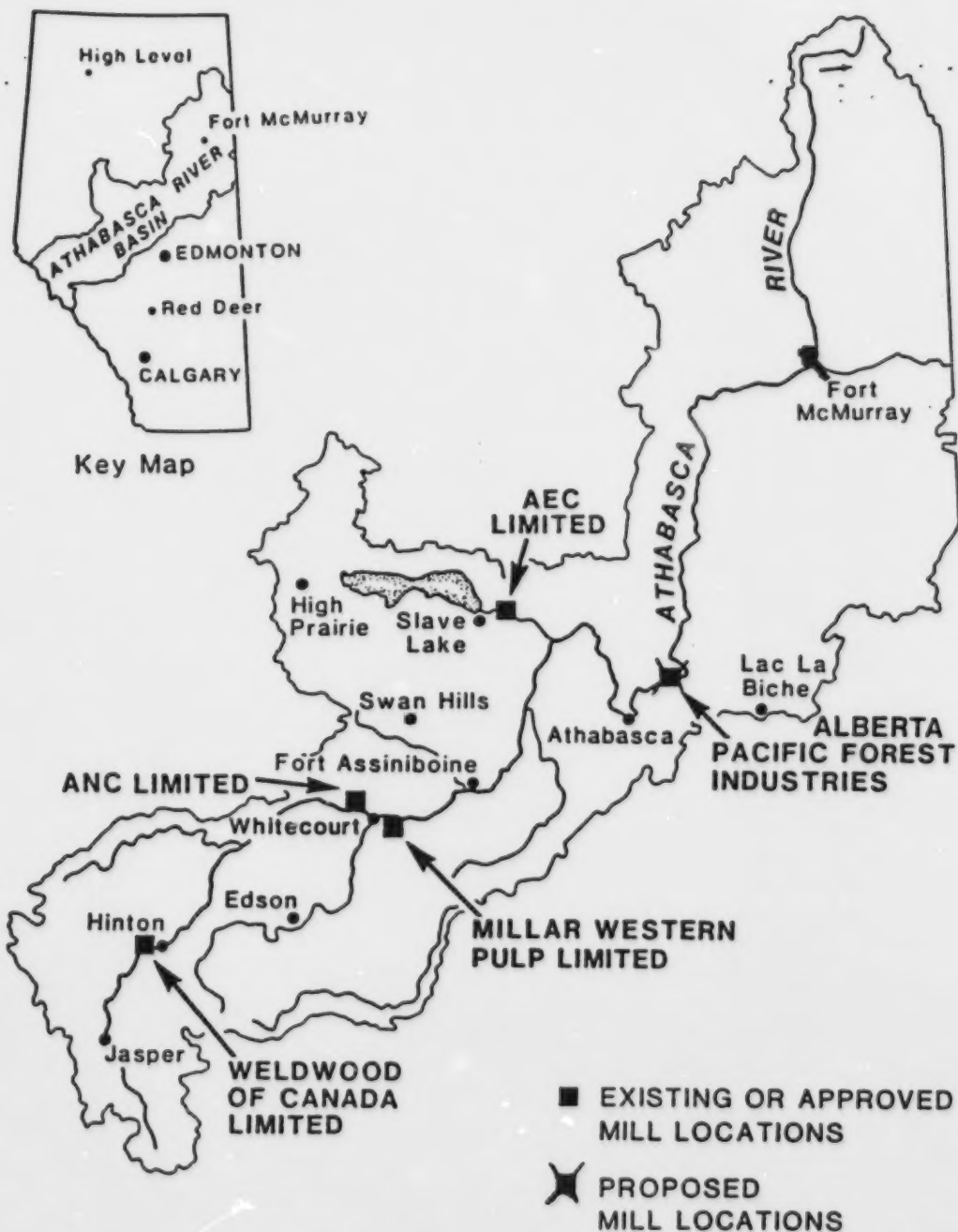
Excursions from those levels have resulted in mortality of stock at the Alberta Environmental Centre. Example, 100% mortality in rainbow trout held at 45 to 50% saturation (4 to 5 mg O₂/L at 15°C) at the Alberta Environmental Centre.



MODELLING APPLICATIONS LICENSING OF INDUSTRIAL PLANTS

by
I. Mackenzie
Water Quality Branch
Alberta Environment

Ian Mackenzie discussed the predictive modelling scenarios of dissolved oxygen levels in the Athabasca River relative to several configurations of anticipated pulp mill loading discharges during winter low river flow conditions. What follows are reproductions of visual aids and other materials used in the presentation.



PULP MILL LOCATIONS ATHABASCA RIVER BASIN

Alberta
ENVIRONMENT

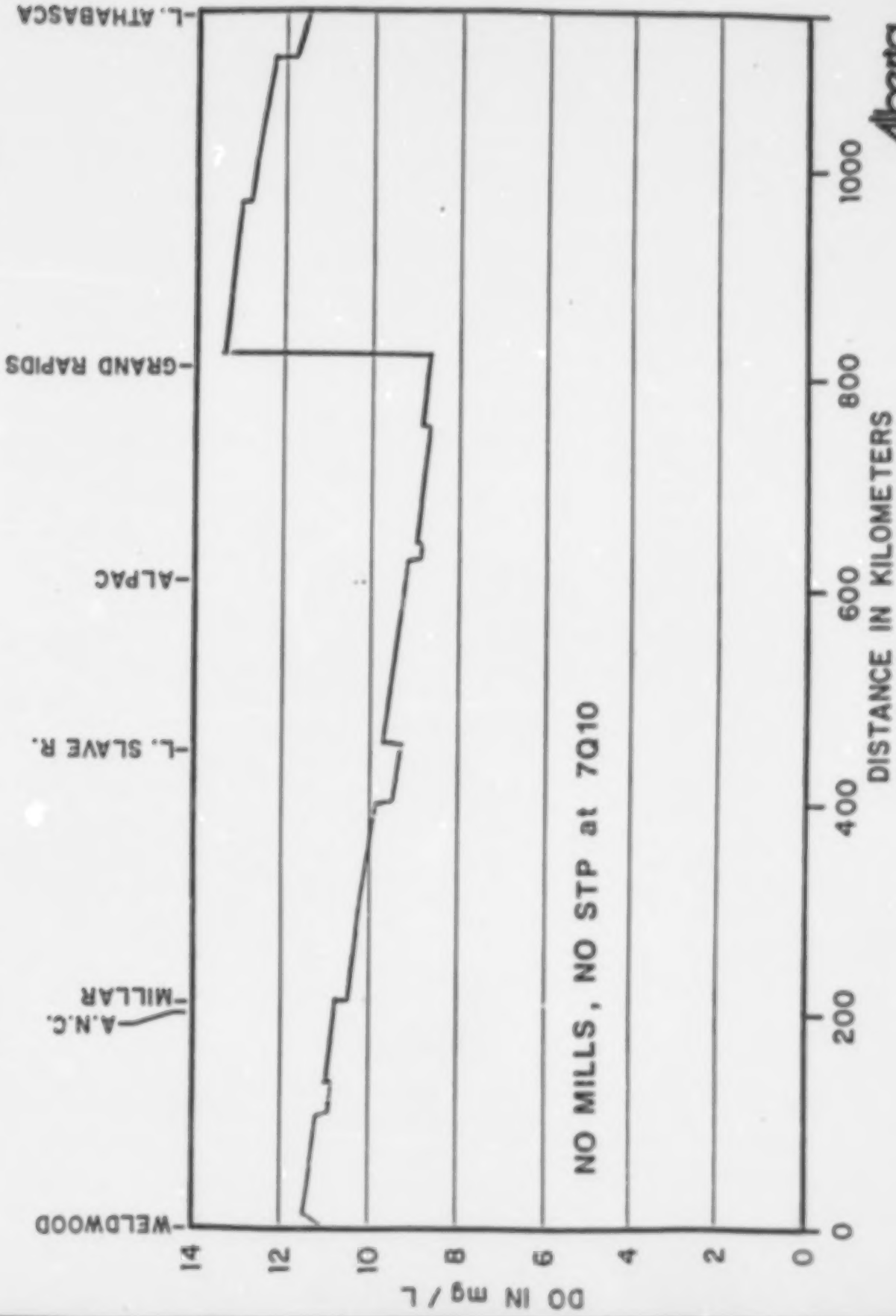
- LICENCE STANDARD
- DISSOLVED OXYGEN OBJECTIVE

DESIGN STANDARD CRITERIA

- 7Q10 FLOW
- FULL INDUSTRIAL DEVELOPMENT
- ALL MILLS DISCHARGING AT LICENCE LIMITS
- 5 MG/L MINIMUM DISSOLVED OXYGEN

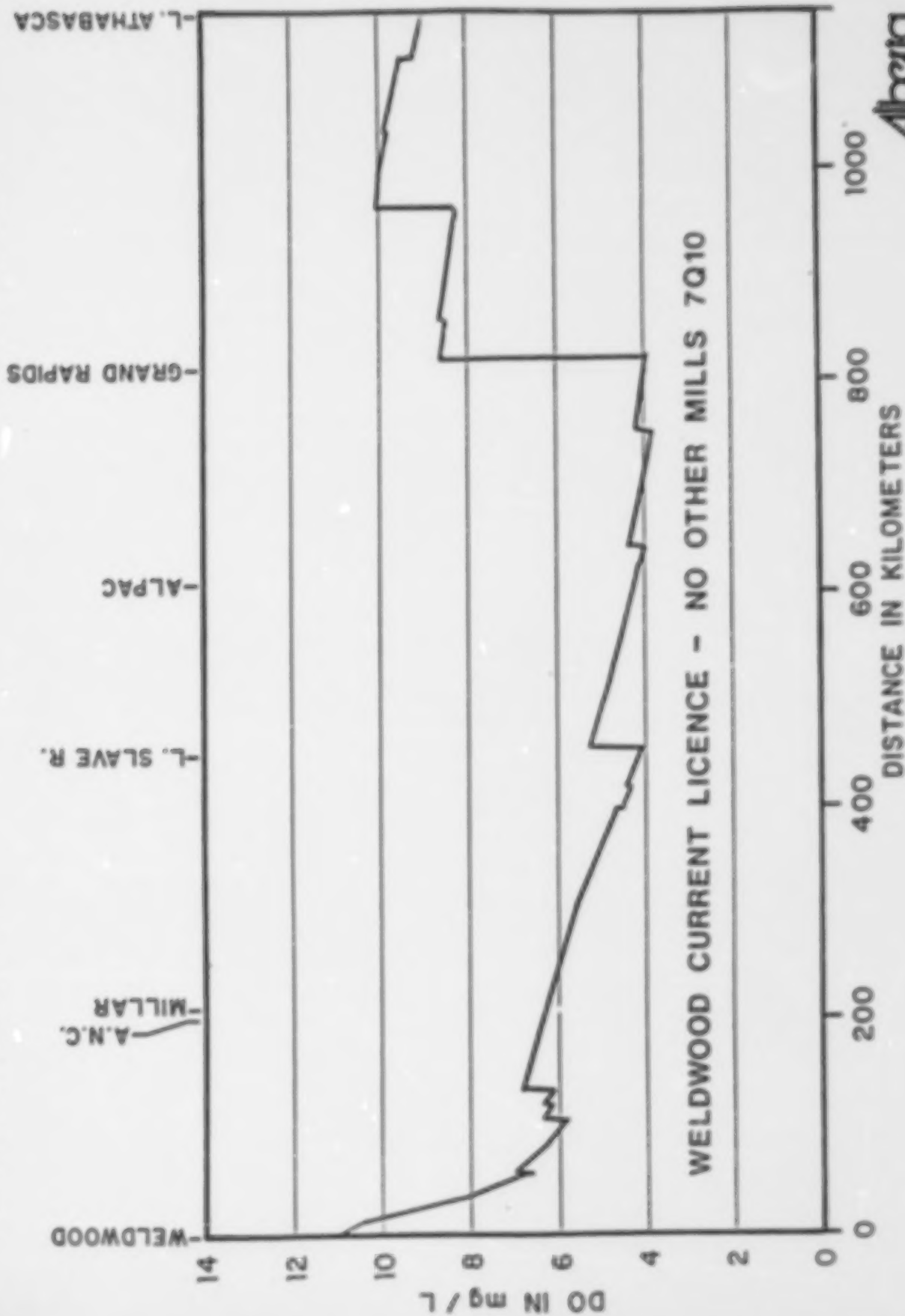
DO CHARACTERISTICS

ATHABASCA RIVER



DO CHARACTERISTICS

ATHABASCA RIVER



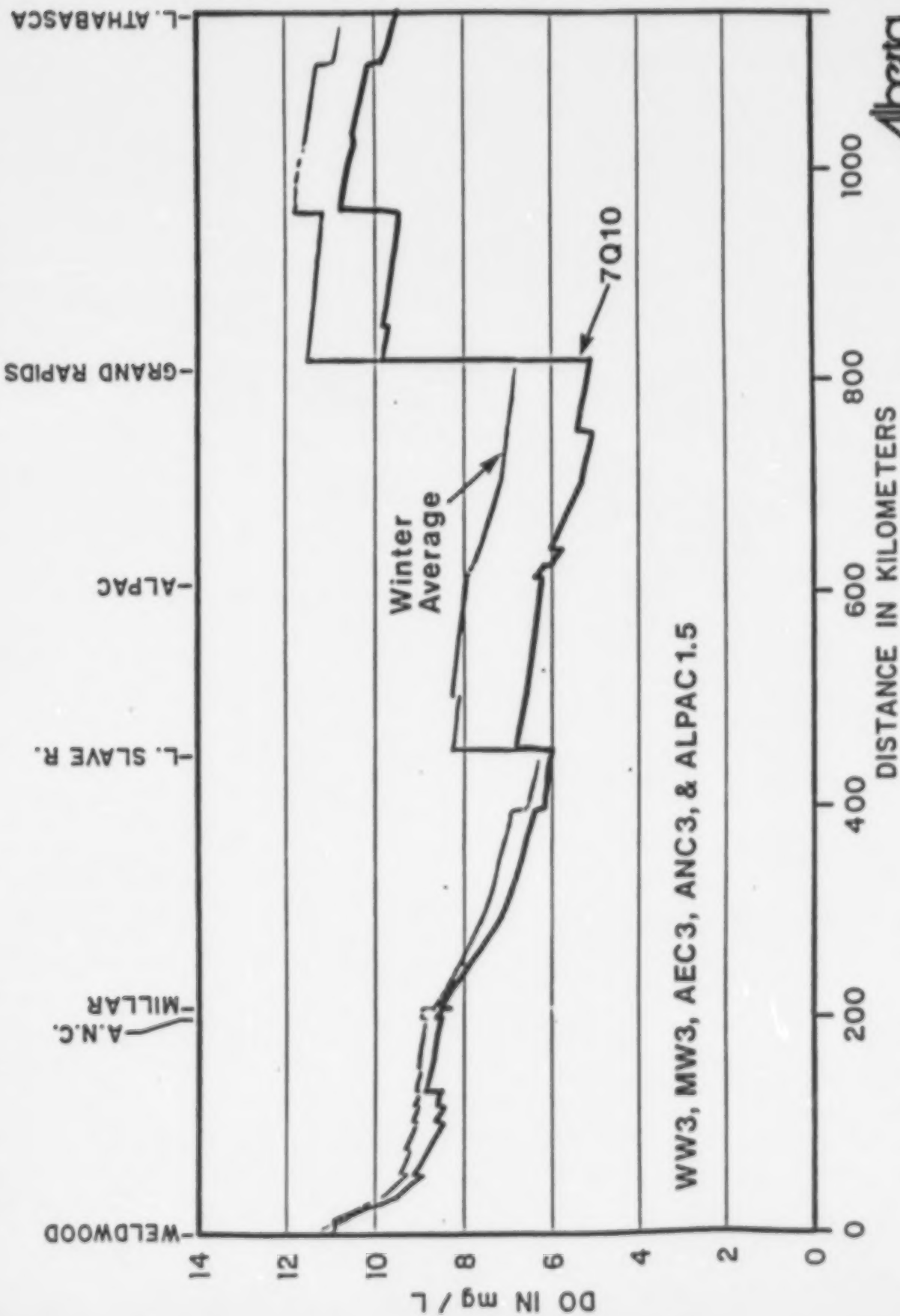
DO CHARACTERISTICS

ATHABASCA RIVER



DO CHARACTERISTICS

ATHABASCA RIVER



**CONDITIONS REQUIRED TO REACH
5.0 MG/L DISSOLVED OXYGEN**

- IT MUST BE MARCH AND ICE COVER
- 7Q10 FLOW
- ALL MILLS MUST BE DISCHARGING
AT THEIR LICENCE LIMIT
- ALL MILLS MUST HAVE BEEN DISCHARGING
AT THEIR LICENCE LIMITS FOR THE
PREVIOUS THREE MONTHS

TERMS, CONDITIONS AND REQUIREMENTS ATTACHED TO LICENCE

6 Amend Note b. by adding subsection g

- g. The 1-day maximum BOD₅ loading is 10,200 kg BOD₅. During times when the Athabasca River flows at Whitecourt downstream of the confluence of the McLeod River and the Athabasca River are less than 55 m³/s, the 1-day maximum BOD₅ loading guideline, Y, shall be calculated according to the following formula (which is also depicted graphically in Figure 1):

$$Y = 246.43(Q_w) - 3278.57$$

Where: Y = 1-day maximum loading in kg BOD₅

Q_w = River flow (m³/s) at Whitecourt, downstream of the McLeod, Athabasca River confluence.

The licensee shall estimate the flow at Whitecourt according to the following formulae:

$$Q_w = Q_H + 18 \quad \text{January, February}$$

$$Q_w = Q_H + 21 \quad \text{March}$$

Where: Q_H = flow at Hinton Hydrometric Station # 07AD002

Notwithstanding the BOD₅ loadings specified in Table 1, and clause c., Table 1, the maximum loading prescribed by these formulae is considered a guideline only. The licensee shall however, make all efforts to comply with the guideline. If the licensee fails to meet the guideline, he shall, within 24 hours, report the incident to the Director of Pollution Control Division. Also, in failing to meet the guideline, the licensee shall immediately measure the dissolved oxygen in the Athabasca River just upstream of the confluence of the Lesser Slave River and report this information to the Director of Pollution Control within 24 hours. The dissolved oxygen shall be measured at a sample frequency of at least 3 equally spaced (in time) samples over a one hour period for each day of measurement. If the dissolved oxygen is found to be at or less than 5 mg/L at this location, the licensee shall immediately curtail his BOD₅ loading to whatever level is necessary to comply with the 5 mg/L dissolved oxygen restriction. This clause will be revised by January 31, 1990.

7. Amend Table 1 by changing the Table heading "Sample Frequency" to "Sample and Analysis Frequency".

DATED January 30, 1989


J.C. LACK, DIRECTOR

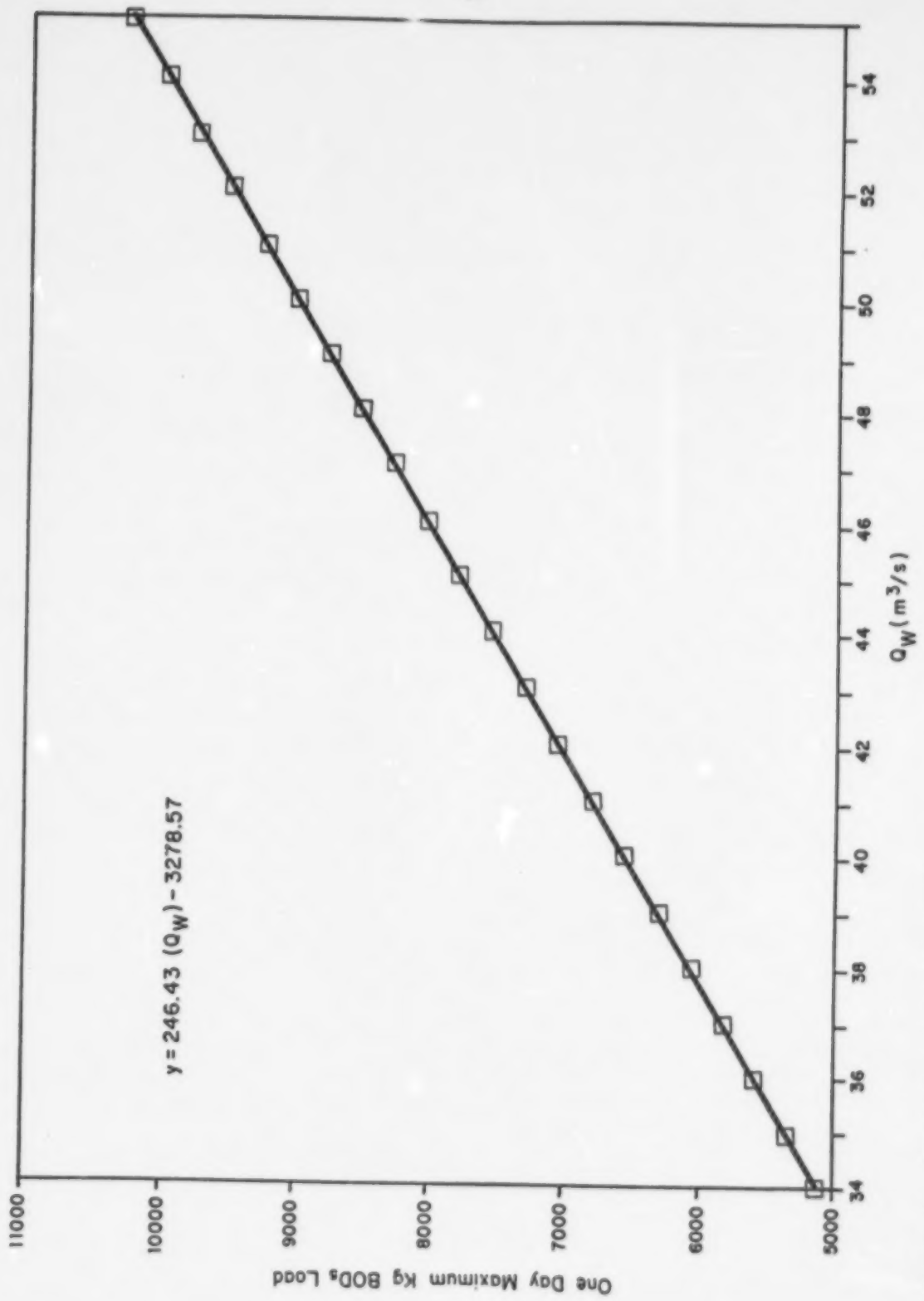


Figure 1. One day maximum BOD₅ load.

MILL EFFLUENT BOD PERFORMANCE HISTORY ATHABASCA RIVER

BOD (Kg/d) (Thousands)



WELDWOOD AEC MILLAR ALPAC ANC ESTIMATED WELDWOOD

1990-1993 REPRESENT STANDARDS
ACTUAL PERFORMANCE WILL BE LESS

FISHERIES HABITAT PROTECTION GUIDELINES
GUIDELINE NO. 6

by
A. Locke
Alberta Forestry, Lands and Wildlife

Allan Locke discussed the framework of the guidelines which are reproduced as an annex in the following paper "Timing Constraints on Fisheries in the Athabasca River Based on Guideline No. 6."



TIMING CONSTRAINTS ON FISHERIES IN THE
ATHABASCA RIVER BASED ON GUIDELINE NO. 6

by
P. Shewchuk
Standards Research and Development Branch
Alberta Environment

1. INTRODUCTION

Seven species of the Salmonidae family are present in the Athabasca River. Five species including lake whitefish, mountain whitefish, lake trout, dolly varden (bull trout), and brook trout spawn in the fall. Arctic grayling and rainbow trout spawn during the spring. The remaining non-salmonidae warm water species including northern pike, goldeye, yellow perch, and walleye are spring spawners (Table 1).

2. FISHERIES TIMING CONSTRAINTS

Fisheries Habitat Protection Guideline No. 6 (Appendix) provides a general range of timing constraints for the protection of incubating eggs and young fry as it relates to construction activity and man-induced siltation in and around water courses or water bodies. According to these data, the timing constraint periods for all species occurs through all seasons and months of the year.

3. DISSOLVED OXYGEN REQUIREMENTS

In salmonid spawning habitats, the water column concentration of dissolved oxygen should be 9.5 mg/L so that the interstitial concentration is 6.5 mg/L (Canadian Water Quality Guidelines) to protect cold water early life stages. The guidelines for early life stages applies from spawning through to 30 days after hatching. The guideline for early life stages is intended to apply only where and when these stages occur. The guideline is protective under worst-case conditions (i.e., for wasteload allocation and waste treatment plant design). When the guideline is applied to predictive modelling assessments, conditions are expected to be better than the guideline nearly all of the time at most sites. In conducting wasteload allocation studies, the choice of temperature and stream flow in the models is important. The best option would be to use temperatures and stream flow similar to those expected in the receiving water over the critical dissolved oxygen period.

4. FISHERIES HABITAT

Current knowledge and existing data gaps on fish ecology and production in the Athabasca River basin are documented in the report "The Fish and Fisheries of the Athabasca River Basin, Status and Environmental

Table 1. Timing constraints on fisheries in the Athabasca River.

SPECIES	SPAWNING PERIOD	GENERAL TIMING CONSTRAINTS
Arctic Grayling*	May-June	Apr.20-July 5
Lake Whitefish*	Oct.-Dec.	Oct. 1-May 30
Mountain Whitefish*	Oct.-Nov.	Sept. 10-Apr. 5
Lake Trout*	mid-Sept.-Oct.	Sept. 10-Apr. 5
Dolly Varden*	fall	Sept. 1-Mar. 25
Brook Trout*	Sept.-Oct.	Oct. 1-Mar. 25
Rainbow Trout*	late spring-early summer	May 15-Aug. 15
Northern Pike	early spring	Apr. 15-July 15
Goldeye	spring	May 15-Aug. 15
Yellow Perch	spring	Apr. 15-July 1
Walleye	spring	Apr. 15-June 30

* Salmonidae.

Requirements, March 31, 1984." Fisheries in the Athabasca basin were regionalized into three upper, two central, and two lower sub-basins which drain into three Athabasca River mainstem sub-basins.

These three sub-basins of the Athabasca River mainstem serve as a major migratory route for important fish species in the region. Fish utilize the river to reach overwintering, spawning, or summer feeding-rearing habitat. For instance, as many as a million lake whitefish leave Athabasca in summer to reach fall spawning habitat upstream of Fort McMurray. The longnose sucker exhibits a similar type of migratory behaviour in late winter or the spring. Suckers, dolly varden, burbot, arctic grayling, and mountain whitefish also use the Athabasca mainstem as a primary migratory route into tributary basins. In essence, the mainstem river section of the Athabasca functions as a linking corridor for fishes distributed among the numerous sub-basins (Table 2).

The mainstem of the principal rivers of the 10 sub-basins provide approximately 4390 km of fish habitat which can be roughly divided as providing 1500 km (34%) cold water habitat (supporting mainly trout and whitefish), 2250 km (51%) warm water habitat (supporting mainly pike, walleye, and goldeye), and 640 km (15%) transition zone intermediate between the two.

5. RESEARCH NEEDS

Current applicability of the timing constraint periods listed in Table 1 to the resident fisheries species listed in Table 2 require verification.

Updated knowledge and consensus of actual fish production levels, species, occurrence, fish migration routes, and site specific critical habitat areas should be established and used in setting appropriate ambient river water quality dissolved oxygen objectives for aquatic life protection, assessing field survey monitoring, and for predictive modelling purposes.

References

- McCart, P. and R. Wallace. 1984. The fish and fisheries of the Athabasca River Basin, status and environmental requirements; March 31, 1984. Alberta Environment. QL 626.5 A3 W193.

Table 2. Athabasca Sub-Basin - predominant species.

	COLD WATER SPECIES	WARM WATER SPECIES
<u>Upper Sub-Basin</u>		
Jasper National Park	Rainbow Trout	
Berland	Rainbow Trout	
McLeod	Rainbow Trout	
<u>Central Sub-Basin</u>		
Pembina	Rainbow Trout Brook Trout	Walleye
Lesser Slave	Mountain Whitefish Brown Trout	Pike Walleye Perch
<u>Lower Sub-Basin</u>		
Lac La Biche	Lake Whitefish Lake Trout	Walleye Pike
Clearwater	Arctic Grayling	Walleye
<u>Athabasca Sub-Basin</u>		
Athabasca I	Arctic Grayling Rainbow Trout Eastern Brook Trout	
Athabasca II	Arctic Grayling Lake Whitefish	Walleye Long-nose Sucker
Athabasca III	Arctic Grayling Lake Whitefish	Walleye Northern Pike Yellow Perch Trout-Perch Goldeye Long-nose Sucker White Suckers

ANNEX A:

FISHERIES HABITAT PROTECTION GUIDELINES



FISHERIES HABITAT PROTECTION GUIDELINES

GUIDELINE NO. 6DATE: January, 1986CONCERNING: TIMING CONSTRAINTS ON CONSTRUCTION IN AND AROUND WATERCOURSES

INTENT: To protect various fish species during critical spawning, hatching and migration periods from activities associated with construction in and around watercourses or waterbodies.

GUIDELINES: These guidelines are based on existing knowledge and are subject to change as more information becomes available. Consult the Fisheries Habitat Section for the latest information.

1. The province of Alberta is divided into nine major drainage basins (Figure 1). When one or more fish species of concern occurs in a watercourse or waterbody within a given drainage basin, construction in and around that watercourse or waterbody should not occur during the general timing constraint as outlined in Tables 1-16 without approval of a Habitat Biologist. Spawning periods, incubation dates and general timing constraints are identified for the nine major drainage basins for the following species of commercial and sport fish:

a) Lake Sturgeon	<u>Acipenser fulvescens</u>	Spring spawning
b) Arctic Grayling	<u>Thymallus arcticus</u>	Spring spawning
c) Lake Whitefish	<u>Coregonus clupeaformis</u>	Fall spawning
d) Mountain Whitefish	<u>Prosopium williamsoni</u>	Fall spawning
e) Lake Trout	<u>Salvelinus namaycush</u>	Fall spawning
f) Dolly Varden	<u>Salvelinus confluentus</u>	Fall spawning
g) Brook Trout	<u>Salvelinus fontinalis</u>	Fall spawning
h) Brown Trout	<u>Salmo trutta</u>	Fall spawning
i) Cutthroat Trout	<u>Salmo clarki</u>	Spring spawning
j) Rainbow Trout	<u>Salmo gairdneri</u>	Spring spawning
k) Golden Trout	<u>Salmo aguabonita</u>	Spring spawning
l) Northern Pike	<u>Esox lucius</u>	Spring spawning
m) Goldeye*	<u>Hiodon alosoides</u>	Spring spawning
n) Yellow Perch	<u>Perca flavescens</u>	Spring spawning
o) Sauger	<u>Stizostedion canadense</u>	Spring spawning
p) Walleye	<u>Stizostedion vitreum vitreum</u>	Spring spawning

2. Where precise information in species composition for a specific stream or section of stream is available, timing constraints may be adjusted accordingly by a Fishery Officer.

* Also includes Mooneye Hiodon tergisus.

BACKGROUND: Many species of fish undertake migrations and may congregate in localized areas during their spawning period. Optimal production is only achieved if reproductive activities can occur during the specific time periods and under the environmental conditions to which the species' life cycle is adapted. For example, spawning migration delays for periods of as little as a few days can cause significant declines in egg production of some species of fish. A decline in successful spawning may be attributed to a delay in fish movement which in turn causes fish to overcrowd and attempt to spawn on unsuitable substrate. Reduced egg fertility and in some cases, re-absorption of eggs will also result and contribute to fish losses. Acceptable spawning habitat for some species of fish may only exist in certain sections of the watercourse, and spawning in less acceptable locations will contribute to a reduction in egg survival. The eggs of fish are extremely sensitive to those conditions associated with waterflow, oxygen availability, the presence of toxic materials, and the deposition of silt. Due to the characteristics of the reproductive activities of fish, they can be seriously impacted by construction activities which result in:

1. Obstruction of fish passage by;
 - a) fills which create total or partial blockage of the watercourse,
 - b) improperly installed or designed culverts that create outfalls or velocity barriers,
 - c) reduction of water depths to unacceptable levels through excessive water removal,
 - d) production of extended periods of point disturbance in or near watercourses causing avoidance reactions by migrants, and
 - e) sufficiently altering water quality in a portion of a waterbody to cause avoidance of the area by fish.
2. Direct lethal effects by;
 - a) use of explosives in watercourses,
 - b) producing extremely high levels of turbidity, and
 - c) use of toxic chemicals in watercourses.
3. Increase egg/fry mortality by;
 - a) causing siltation resulting in reduced percolation of water through spawning beds and also preventing escapement of sac fry from the gravel,
 - b) physical disturbance of incubating eggs, and
 - c) dewatering or freezing of incubating eggs.
4. Loss of fish food items by covering the habitat (gravel rock) of these organisms with silt.

Fall spawning fish release their eggs onto a particular substrate in September, October or November and these eggs remain in an egg stage, developing slowly, until March or April. Spring spawning fish are vulnerable for a shorter period of time from April to June or July. The egg and fry stages tend to be the most vulnerable periods of time in the life cycle of fish but other stages including the adult may be negatively impacted by construction activities in or near watercourses.

IMPLEMENTATION: Timing constraints for construction could conceivably be used for any type of works that might cause a release of sediment or a physical disturbance in a particular watercourse or waterbody. These guidelines are particularly necessary in pipeline and road construction across watercourses. These constraints will generally be placed on letters of authority through Public Lands Dispositions Section or on water licences and permits through Alberta Environment.

LEGISLATIVE REFERENCES:

Fisheries Act
Public Lands Act
Water Resources Act

Table 1 - 16. Timing Concerns for Various Species of Alberta Fishes.

Table 1. Lake Sturgeon Acipenser fulvescens spring spawner

<u>Drainage Basin</u>	<u>Spawning Time</u>	<u>Incubation Complete</u>	<u>General Timing Constraint</u>
South Saskatchewan River	June 25 to July 15	July 23	June 20 to August 1
North Saskatchewan River	June 25 to July 15	July 23	June 20 to August 1

Table 2. Arctic Grayling Thymallus arcticus spring spawner

<u>Drainage Basin</u>	<u>Spawning Time</u>	<u>Incubation Complete</u>	<u>General Timing Constraint</u>
Churchill River	April 23 to April 30	June 22	April 18 to June 27
Athabasca River	April 23 to June 10	June 30	April 20 to July 5
Peace River	April 23 to June 10	June 30	April 20 to July 5
Hay River	April 23 to June 10	June 30	April 20 to July 5

Table 3. Lake Whitefish Coregonus clupeaformis fall spawner

<u>Drainage Basin</u>	<u>Spawning Time</u>	<u>Incubation Complete</u>	<u>General Timing Constraint</u>
South Saskatchewan River	Sept. 25 to Dec. 30	May 25	Sept. 28 to May 30
North Saskatchewan River	Sept. 28 to Dec. 30	May 25	Sept. 28 to May 30
Churchill River	Oct. 1 to Dec. 5	May 25	Sept. 28 to May 30
Athabasca River	Oct. 1 to Jan. 30	May 25	Oct. 1 to May 30
Peace River	Oct. 1 to Jan. 30	May 25	Oct. 1 to May 30
Hay River	Oct. 1 to Jan. 30	May 25	Oct. 1 to May 30
Slave River	Oct. 1 to Jan. 30	May 25	Oct. 1 to May 30
Liard River	Oct. 1 to Jan. 30	May 25	Oct. 1 to May 30

Table 1 - 16. Timing Concerns for Various Species of Alberta Fishes (cont.).

Table 4. Mountain Whitefish Prosopium williamsoni fall spawner

<u>Drainage Basin</u>	<u>Spawning Time</u>	<u>Incubation Complete</u>	<u>General Timing Constraint</u>
Milk River	Sept. 1 to Oct. 23	April 1	Sept. 1 to April 5
South Saskatchewan River	Sept. 15 to Oct. 23	April 1	Sept. 10 to April 5
North Saskatchewan River	Sept. 15 to Oct. 23	April 1	Sept. 10 to April 5
Athabasca River	Sept. 15 to Oct. 23	April 1	Sept. 10 to April 5
Peace River	Sept. 15 to Oct. 23	April 1	Sept. 10 to April 5

Table 5. Lake Trout Salvelinus namaycush fall spawner

<u>Drainage Basin</u>	<u>Spawning Time</u>	<u>Incubation Complete</u>	<u>General Timing Constraint</u>
South Saskatchewan River	Sept. 15 to Oct. 15	April 1	Sept. 10 to April 5
North Saskatchewan River	Sept. 15 to Oct. 15	April 1	Sept. 10 to April 5
Churchill River	Sept. 15 to Oct. 15	April 1	Sept. 10 to April 5
Athabasca River	Sept. 15 to Oct. 15	April 1	Sept. 10 to April 5
Peace River	Sept. 15 to Oct. 15	April 1	Sept. 10 to April 5
Slave River	Sept. 15 to Oct. 15	April 1	Sept. 10 to April 5

Table 1 - 16. Timing Concerns for Various Species of Alberta Fishes (cont.)

Table 6. Dolly Varden Salvelinus confluentus fall spawner

<u>Drainage Basin</u>	<u>Spawning Time</u>	<u>Incubation Complete</u>	<u>General Timing Constraint</u>
South Saskatchewan River	Sept. 1 to Oct. 1	March 20	Sept. 1 to March 25
North Saskatchewan River	Aug. 15 to Oct. 1	March 20	Aug. 10 to March 25
Athabasca River	Sept. 1 to Oct. 1	March 20	Sept. 1 to March 25
Peace River	Sept. 1 to Oct. 1	March 20	Sept. 1 to March 25

Table 7. Brook Trout Salvelinus fontinalis fall spawner

<u>Drainage Basin</u>	<u>Spawning Time</u>	<u>Incubation Complete</u>	<u>General Timing Constraint</u>
South Saskatchewan River	Sept. 15 to Nov. 15	March 20	Sept. 15 to March 25
North Saskatchewan River	Sept. 15 to Nov. 15	March 20	Sept. 15 to March 25
Athabasca River	Oct. 1 to Nov. 15	March 20	Oct. 1 to March 25

Table 8. Brown Trout Salmo trutta fall spawner

<u>Drainage Basin</u>	<u>Spawning Time</u>	<u>Incubation Complete</u>	<u>General Timing Constraint</u>
Milk River	Sept. 15 to Nov. 15	March 20	Sept. 15 to March 25
South Saskatchewan River	Sept. 15 to Nov. 15	March 20	Sept. 15 to March 25
North Saskatchewan River	Oct. 1 to Nov. 15	March 20	Sept. 25 to March 25

Table 1 - 16. Timing Concerns for Various Species of Alberta Fishes (cont.)

Table 9. Cutthroat Trout Salmo clarki spring spawner

<u>Drainage Basin</u>	<u>Spawning Time</u>	<u>Incubation Complete</u>	<u>General Timing Constraint</u>
South Saskatchewan River	June 2 to June 25	August 10	May 27 to Aug. 15
North Saskatchewan River	May 20 to June 25	August 10	May 20 to Aug. 15

Table 10. Rainbow Trout Salmo gairdneri spring spawner

<u>Drainage Basin</u>	<u>Spawning Time</u>	<u>Incubation Complete</u>	<u>General Timing Constraint</u>
Milk River	May 15 to June 15	August 15	May 15 to Aug. 15
South Saskatchewan River	May 1 to June 15	July 15	May 1 to July 15
North Saskatchewan River	April 15 to June 15	July 15	April 15 to July 15
Athabasca River	May 15 to June 15	August 15	May 15 to Aug. 15

Table 11. Golden Trout Salmo aguabonita spring spawner

<u>Drainage Basin</u>	<u>Spawning Time</u>	<u>Incubation Complete</u>	<u>General Timing Constraint</u>
South Saskatchewan River	June 1 to June 30	August 21	May 25 to August 25

Table 1 - 16. Timing Concerns for Various Species of Alberta Fishes (cont.)

Table 12. Northern Pike Esox lucius spring spawner

<u>Drainage Basin</u>	<u>Spawning Time</u>	<u>Incubation Complete</u>	<u>General Timing Constraint</u>
Milk River	May 1 to June 1	July 1	May 1 to July 1
South Saskatchewan River	May 1 to June 1	July 1	May 1 to July 1
North Saskatchewan River	April 15 to May 20	July 1	April 15 to July 1
Churchill River	April 15 to May 20	July 1	April 15 to July 1
Athabasca River	April 15 to June 10	July 15	April 15 to July 15
Peace River	April 15 to June 10	July 15	April 15 to July 15
Hay River	April 15 to June 10	July 15	April 15 to July 15
Slave River	April 15 to June 10	July 15	April 15 to July 15
Liard River	April 15 to June 10	July 15	April 15 to July 15

Table 13*. Goldeye Hiodon alosoides spring spawner

<u>Drainage Basin</u>	<u>Spawning Time</u>	<u>Incubation Complete</u>	<u>General Timing Constraint</u>
South Saskatchewan River	May 15 to July 15	August 15	May 15 to Aug. 15
North Saskatchewan River	May 15 to July 15	August 15	May 15 to Aug. 15
Athabasca River	May 15 to July 15	August 15	May 15 to Aug. 15
Peace River	May 15 to July 15	August 15	May 15 to Aug. 15
Slave River	May 15 to July 15	August 15	May 15 to Aug. 15

* Mooneye Hiodon tergisus follows the same drainage basins and timing constraints as goldeye.

Table 1 - 16. Timing Concerns for Various Species of Alberta Fishes (cont.)

Table 14. Yellow Perch Perca flavescens spring spawner

<u>Drainage Basin</u>	<u>Spawning Time</u>	<u>Incubation Complete</u>	<u>General Timing Constraint</u>
South Saskatchewan River	April 15 to June 1	July 1	April 15 to July 1
North Saskatchewan River	April 15 to June 1	July 1	April 15 to July 1
Churchill River	April 15 to June 1	July 1	April 15 to July 1
Athabasca River	April 15 to June 1	July 1	April 15 to July 1
Peace River	April 15 to June 1	July 1	April 15 to July 1
Slave River	April 15 to June 1	July 1	April 15 to July 1

Table 15. Sauger Stizostedion canadense spring spawner

<u>Drainage Basin</u>	<u>Spawning Time</u>	<u>Incubation Complete</u>	<u>General Timing Constraint</u>
Milk River	May 1 to June 1	June 30	May 1 to June 30
South Saskatchewan River	May 1 to June 1	June 30	May 1 to June 30
North Saskatchewan River	May 1 to June 1	June 30	May 1 to June 30

Table 1 - 16. Timing Concerns for Various Species of Alberta Fishes (cont.)

Table 16. Walleye Stizostedion vitreum vitreum

<u>Drainage Basin</u>	<u>Spawning Time</u>	<u>Incubation Complete</u>	<u>General Timing Constraint</u>
South Saskatchewan River	April 15 to June 1	June 30	April 15 to June 30
North Saskatchewan River	April 15 to June 1	June 30	April 15 to June 30
Churchill River	April 15 to June 1	June 30	April 15 to June 30
Athabasca River	April 15 to June 1	June 30	April 15 to June 30
Peace River	April 15 to June 1	June 30	April 15 to June 30
Hay River	April 15 to June 1	June 30	April 15 to June 30
Slave River	April 15 to June 1	June 30	April 15 to June 30
Liard River	April 15 to June 1	June 30	April 15 to June 30

DISSOLVED OXYGEN REQUIREMENTS

- IN SALMONID SPAWNING HABITATS, THE WATER COLUMN CONCENTRATION OF DISSOLVED OXYGEN SHOULD BE 9.5 mg/L SO THAT THE INTERSTITIAL CONCENTRATION IS 6.5 mg/L (CANADIAN WATER QUALITY GUIDELINES) TO PROTECT COLD WATER EARLY LIFE STAGES.
- THE GUIDELINES FOR EARLY LIFE STAGES APPLIES FROM SPAWNING THROUGH TO 30 DAYS AFTER HATCHING AND IS INTENDED TO APPLY ONLY WHERE AND WHEN THESE STAGES OCCUR.
- THE GUIDELINE IS PROTECTIVE UNDER WORST CASE CONDITIONS (i.e., FOR WASTELOAD ALLOCATION AND WASTE TREATMENT PLANT DESIGN). WHEN THE GUIDELINE IS APPLIED TO PREDICTIVE MODELLING ASSESSMENTS, CONDITIONS ARE EXPECTED TO BE BETTER THAN THE GUIDELINE NEARLY ALL OF THE TIME AT MOST SITES.

W5

WHO - FISH HABITAT
WHAT - FISHERIES PROTECTION = f (DISSOLVED OXYGEN)
WHEN - CRITICAL SPAWNING, HATCHING, MIGRATION PERIODS
WHY - FISHERIES PROTECTION
WHERE - ?

FISHERIES TIMING CONTRAINTS
(SPAWNING, HATCHING, MIGRATION)
ATHABASCA RIVER

	1990	1990	1990	1990	1990	1990
	SMTWTFS	SMTWTFS	SMTWTFS	SMTWTFS	SMTWTFS	SMTWTFS
	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6	1 2 3 4 5 6
JAN	7 8 9 10 11 12 13	7 8 9 10 11 12 13	7 8 9 10 11 12 13	7 8 9 10 11 12 13	7 8 9 10 11 12 13	7 8 9 10 11 12 13
FEB	14 15 16 17 18 19 20	14 15 16 17 18 19 20	14 15 16 17 18 19 20	14 15 16 17 18 19 20	14 15 16 17 18 19 20	14 15 16 17 18 19 20
MAR	21 22 23 24 25 26 27	21 22 23 24 25 26 27	21 22 23 24 25 26 27	21 22 23 24 25 26 27	21 22 23 24 25 26 27	21 22 23 24 25 26 27
APR	28 29 30 31 1 2 3	28 29 30 31 1 2 3	28 29 30 31 1 2 3	28 29 30 31 1 2 3	28 29 30 31 1 2 3	28 29 30 31 1 2 3
MAY	4 5 6 7 8 9 10	4 5 6 7 8 9 10	4 5 6 7 8 9 10	4 5 6 7 8 9 10	4 5 6 7 8 9 10	4 5 6 7 8 9 10
JUN	11 12 13 14 15 16 17	11 12 13 14 15 16 17	11 12 13 14 15 16 17	11 12 13 14 15 16 17	11 12 13 14 15 16 17	11 12 13 14 15 16 17
JUL	18 19 20 21 22 23 24	18 19 20 21 22 23 24	18 19 20 21 22 23 24	18 19 20 21 22 23 24	18 19 20 21 22 23 24	18 19 20 21 22 23 24
AUG	25 26 27 28 1 2 3	25 26 27 28 1 2 3	25 26 27 28 1 2 3	25 26 27 28 1 2 3	25 26 27 28 1 2 3	25 26 27 28 1 2 3
SEP	4 5 6 7 8 9 10	4 5 6 7 8 9 10	4 5 6 7 8 9 10	4 5 6 7 8 9 10	4 5 6 7 8 9 10	4 5 6 7 8 9 10
OCT	11 12 13 14 15 16 17	11 12 13 14 15 16 17	11 12 13 14 15 16 17	11 12 13 14 15 16 17	11 12 13 14 15 16 17	11 12 13 14 15 16 17
NOV	18 19 20 21 22 23 24	18 19 20 21 22 23 24	18 19 20 21 22 23 24	18 19 20 21 22 23 24	18 19 20 21 22 23 24	18 19 20 21 22 23 24
DEC	25 26 27 28 29 30 31	25 26 27 28 29 30 31	25 26 27 28 29 30 31	25 26 27 28 29 30 31	25 26 27 28 29 30 31	25 26 27 28 29 30 31

ARCTIC
GRAYLINGRAINBOW
TROUTNORTHERN
PIKE

WALLEYE

YELLOW
PERCH

GOLDEYE

FISHERIES TIMING CONSTRAINTS
(SPAWNING, HATCHING, MIGRATION)
ATHABASCA RIVER

	1990	1990	1990	1990	1990
JAN					
FEB					
MAR					
APR					
MAY					
JUN					
JUL					
AUG					
SEP					
OCT					
NOV					
DEC					
	LAKE WHITEFISH	MOUNTAIN WHITEFISH	LAKE TROUT	DOLLY VARDEN	BROOK TROUT

RESEARCH NEEDS

- CURRENT APPLICABILITY OF THE TIMING CONSTRAINT PERIODS TO THE RESIDENT FISHERIES SPECIES REQUIRE VERIFICATION.
- UPDATED KNOWLEDGE OF ACTUAL FISH PRODUCTION LEVELS, SPECIES, OCCURRENCE, FISH MIGRATION ROUTES AND SITE SPECIFIC CRITICAL HABITAT AREAS NEED TO BE ESTABLISHED AND WEIGHTED IN REGARD TO APPROPRIATE AMBIENT RIVER WATER QUALITY DISSOLVED OXYGEN OBJECTIVES FOR AQUATIC LIFE PROTECTION, FIELD SURVEY MONITORING ASSESSMENT, AND PREDICTIVE MODELLING PURPOSES.



FISHERIES PHYSIOLOGICAL RESPONSES
- EXCERPTS FROM NATIONAL RESEARCH COUNCIL
REPORT #13

by
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Standards Research and Development Branch
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1. INTRODUCTION

A large body of literature exists on the oxygen requirements of aquatic organisms as a basis for formulating water-dissolved oxygen quality criteria in Canada. The most current summaries and thorough updating of the literature are included in the Canadian Water Quality Guidelines, March 1987, Chapter 3; Fresh Water Aquatic Life, US EPA Quality Criteria for Water 1986, and the National Research Council of Canada, NRC, Associate Committee on Scientific Criteria for Environmental Quality, Report No. 13 by John C. Davis. Excerpts of these documents are included in the annexes which follow this paper.

2. NATIONAL RESEARCH COUNCIL REPORT NO. 13 (EXCERPTS)

In much of the earlier work, laboratory and field studies could not be correlated. Davis also noted that numerous and often contradictory reports were the result of problem definition (i.e., observations of concentrations of dissolved oxygen causing mortality or equilibrium loss). The approach taken by Davis was to scan the literature and extract information on dissolved oxygen levels where sublethal responses to hypoxia (lowered oxygen) first became apparent (i.e., the incipient sublethal threshold). The oxygen requirements of fish as related to blood oxygen dissociation, ventilation, circulation and respiratory dependence, energetics, behaviour responses, growth, acclimation, interaction with toxic agents, and egg and larvae development are comprehensively discussed by Davis.

Production impairment of invertebrates is not affected in waters where the dissolved oxygen concentration is 8.0 mg/L. Some production impairment occurs at 5.0 mg/L. The acute mortality limit is 4.0 mg/L (US EPA). If, however, all life stages of fish are protected, the invertebrate communities should also be reasonably protected. Oxygen criteria were developed which represented three levels of risk commitment concerning aquatic life (Annex).

Level A - this level represents more or less ideal conditions (i.e., little or no foreseeable harm) and permits little depression of oxygen from full saturation. It represents a level that assures a high degree of safeguard for very important stocks in prime areas.

Level B - at this level some degree of risk (i.e., possibility of moderate harm) to a portion of a fish population exists if the oxygen minimum period is prolonged beyond a few hours.

Level C - at this level a large portion of a given fish population or fish community may be affected by low oxygen. This deleterious effect may be severe (i.e., possibility of severe harm), especially if the oxygen minimum is prolonged beyond a very few hours.

3. SEASONAL CONSIDERATIONS

Table 5 and Figure 1-B of Technical Report No. 13 depicts the range of high degree of fisheries protection (Level A) to a possibility of severe harm if the oxygen minimum is prolonged (Level C).

For example, during late autumn, winter, and early spring, a dissolved oxygen concentration of less than 7 mg/L (54% saturation) for more than a few hours at a temperature of 5°C would present a possibility of moderate harm (Level B) to a mixed population of freshwater fish, including some salmonids. A dissolved oxygen concentration of less than 9.5 mg/L (76% saturation) for more than a few hours at a temperature of 5°C is similarly categorized Level B with respect to potential effects on salmonid larvae and mature eggs of salmonids. Severe harm (Level C) could be sustained at 4.8 mg/L (38% saturation) and 7.0 mg/L (54% saturation) for the mixed population of freshwater fish including salmonids, and the salmonid larvae and mature eggs grouping, respectively.

During the open water summer season, critical dissolved oxygen concentrations at Level B for river temperature of 20°C would be 5.4 mg/L (57% saturation) and 8.1 mg/L (87% saturation) for the mixed population of freshwater fish including salmonids, and the salmonid larvae and mature eggs grouping. Limiting Level C dissolved oxygen concentrations would be 3.6 mg/L (39% saturation) and 6.4 mg/L (71% saturation) respectively.

A N N E X A:

NATIONAL RESEARCH COUNCIL REPORT NO. 13 (EXCERPTS)



NATIONAL RESEARCH COUNCIL OF CANADA
NRC ASSOCIATE COMMITTEE ON SCIENTIFIC CRITERIA
FOR
ENVIRONMENTAL QUALITY
Report No. 13

WATERBORNE DISSOLVED OXYGEN REQUIREMENTS AND CRITERIA
WITH PARTICULAR EMPHASIS ON THE CANADIAN ENVIRONMENT

by

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PART A - SUMMARIES AND CONCLUSIONS

The following section contains brief, general summaries of the theoretical portion (B) of this report. The reader should consult Part B for details and an explanation of how these conclusions were derived. Part A also includes, for quick reference, both a graphical and a diagrammatic presentation of the oxygen criteria derived herein.

OXYGEN REQUIREMENTS OF FISH

Reduction in the level of available oxygen has a marked effect on many physiological, biochemical, and behavioral process in fish. The oxygen level where such effects first become apparent (i.e. the incipient oxygen response threshold) has been used throughout this report in the derivation of oxygen criteria selected to assess adverse effects on fish. Brief summaries of the effects of low oxygen on fish life follow. The reader should refer to Part B of this report for further details.

Restrictions in the supply of oxygen available for metabolic processes including swimming, migrating and feeding are likely caused by hypoxia. Adequate oxygen levels for such activities are necessary for the survival of healthy fish populations. Oxygen requirements of fish are noticeably influenced by season, temperature, and activity. The oxygen tension where respiratory dependence begins is considered an important lower limit for tolerable available oxygen. The effects of hypoxia on metabolic processes and swimming ability, as well as the O_2 levels causing the onset of respiratory dependence, are included in Tables 1, 2, 3 and 4.

Tables 1 to 4 list the incipient oxygen response thresholds for various fish groups and habitats gathered from the literature, with emphasis on Canadian species. The rationale for choosing the reported response and its significance are reported in the following pages (Part B). In most instances, oxygen response thresholds were found in only one form of terminology (e.g. mg O_2 /l) and the corresponding values expressed in other units were calculated from it. Calculations from freshwater fish made use of the reported temperature and the O_2 solubility data from Tables 5 and 6, while those for non-anadromous fish in seawater used the data from Table 8 and an assumed salinity of 28‰. It is stressed that the response levels reported are incipient oxygen levels where effects first become apparent, thus providing a "biological indication" of the onset of hypoxic stress.

Table 1. Summary of incipient oxygen response thresholds for freshwater fish species.

Species	Size	Temperature (°C)	Level of dissolved oxygen				Response to oxygen level	Reference
			PO ₂ mm Hg	ml O ₂ /l	mg O ₂ /l	Percent Satura- tion		
Arctic charr, (<i>Salvelinus alpinus</i>)	--	2±.05	25	1.53	2.18	15.8	"Signs of asphyxia and loss of equilibrium"	Holeton 1973
Brown bullhead (<i>Ictalurus nebulosus</i>)	43-127 g	9-10	60	4.87-4.76	6.95-6.80	38.0	Onset of oxy- gen-dependent oxygen uptake	Grigg 1969
Rainbow trout (<i>Salmo gairdneri</i>)	628-1136 g	20	78	3.20	4.59	50	Blood is not fully satu- rated with oxygen below this level	Irving et al. 1941
Rainbow trout (<i>Salmo gairdneri</i>)	120-250 g	8.5-15	80-100	3.63-5.14	5.18-7.34	50.7-63.7	Circulatory changes occur, including a slowing of heart rate	Randall and Smith 1967
Carp (<i>Cyprinus carpio</i>)	77-350 g	10	50	2.51	3.59	31.7	Standard oxy- gen uptake elevated (de- pressed at lower levels)	Beamish 1964
	30-600 g	20	80	3.29	4.71	51.3		
Carp (<i>Cyprinus carpio</i>)	235-785 g	13.3-25	80	2.74-3.04	5.39-4.34	50.9-51.6	Blood ceases to be fully saturated with O ₂ below this level	Itazawa 1970
Walleye (<i>Stizostedion vitreum</i>)	2 y old	22	35.2-70.4	2.8-1.4	4-2.0	45.3-22.7	Loss of nega- tive photo- taxis (light avoidance be- havior)	Scherer 1971
			70.4-96.8	3.85-2.8	5.5-4.0	45.3-62.3	Increased mo- bility, "darting" be- havior	

Table 1. (Cont'd)

Species	Size	Temperature (°C)	Level of dissolved oxygen				Percent satura- tion	Response to oxygen level	Reference
			P _O ₂ mm Hg	ml O ₂ /l	mg O ₂ /l				
Largemouth bass (<i>Micropterus salmoides</i>)	5-9 cm	-	-	3.15	4.5		-	Some indica- tion of avoidance be- havior	Whitmore et al. 1960
Brook trout (speckled trout) (<i>Salvelinus fontinalis</i>)	682-1136 g	20	77.95	3.21	4.59		50	Marked avoi- dance	Irving et al. 1941
Brook trout (speckled trout) (<i>Salvelinus fontinalis</i>)	17-65 g	5	100	5.66	8.09		63.2	Blood ceases to be fully saturated with oxygen below this level	
		8	80	4.19	5.99		50.7	Onset of oxygen- dependent meta- bolism	
		20	154	6.34	9.06		98.8	Reduced cruis- ing speed	
		5-20	166.9-118.7	6.72-4.82	9.6-6.88		75	Onset of oxy- gen-dependent metabolism	
Brook trout (speckled trout) (<i>Salvelinus fontinalis</i>)	56-140 g	10, 15	80	4.03-3.63	5.75-5.18		50.7- 51.0	Reduced activity at all temperatures	
Brown trout (<i>Salmo trutta</i>)	682-1136 g	20	77.95	3.21	4.59		50	Standard oxygen uptake reduced below this level	Beamish 1964
Rainbow trout (<i>Salmo gairdneri</i>)	13.3±1.4 cm	17±.5	156.6	6.82	9.74		100	Blood ceases to be fully saturated with oxygen below this level	Irving et al. 1941
								Any reduction in oxygen led to more rapid death in cya- nide	Downing 1954

Table 1. (Cont'd)

Species	Size	Temperature (°C)	Level of dissolved oxygen				Response to oxygen level	Reference
			PO ₂ mm Hg	ml O ₂ /l	mg O ₂ /l	Percent satura- tion		
Rainbow trout (<i>Salmo gairdnerii</i>)	20 months old	8-10	78.85-79.95	4.16-3.97	5.94-5.67	50	43% reduction in maximum swimming speed	Jones 1971b
		21-23	77.85-77.6	3.15-3.04	4.50-4.34	50	30% reduction in maximum swimming speed	
Rainbow trout (<i>Salmo gairdnerii</i>)	235-510 g	2.3-13	100	6.11-4.71	8.73-6.74	63.1-63.6	Blood is not fully saturated with oxygen be- low this level	Itazawa 1970
Rainbow trout (<i>Salmo gairdnerii</i>)	-	15	78.45	3.55	5.08	50	Altered res- piratory quotient; little capacity for anaerobic meta- bolism below this level	Kutty 1968a
Rainbow trout (<i>Salmo gairdnerii</i>)	-	15	80-100	3.63-4.53	5.18-6.47	51.0-63.7	Changes in oxygen transfer factor and effectiveness of oxygen ex- change occur	Randall et al. 1967
Rainbow trout (<i>Salmo gairdnerii</i>)	400-600 g	13.5	80	3.74	5.35	51.0	Breathing amplitude and buccal pressure elevated	Hughes and Saunders 1970
Rainbow trout (<i>Salmo gairdnerii</i>)	approx. 300 g	10, 15, 20	80	3.30-4.03	4.71-5.75	50.7-51.3	Blood is not fully satura- ted with oxy- gen below this level	Cameron 1971
Rainbow trout (<i>Salmo gairdnerii</i>)	1-11 g	17.5	93.8	4.05	5.78	60	Toxicity of zinc, lead, copper and phenols in- creased markedly be- low this level	Lloyd 1961 †

Table 1. (Cont'd)

Species	Size	Temperature (°C)	Level of dissolved oxygen				Response to oxygen level	Reference
			PO ₂ mm Hg	ml O ₂ /l	mg O ₂ /l	Percent satura- tion		
Largemouth bass (<i>Micropterus salmoides</i>)	Juvenile	25	92.3-110.7	3.5-4.2	5-6	59.7-71.6	Final (maximum sustained) swimming speed reduced below this level	Dahlberg et al. 1968
Bluegill (<i>Lepomis macrochirus</i>)	5-9 cm	-	-	2.1	3.0	-	Some avoidance behavior	Whitmore et al. 1960
				1.1	1.5	-	Strong avoid- ance behavior	

Table 4. Summary of incipient oxygen response thresholds for freshwater and marine fish eggs and larvae.

Species	Size	Temperature (°C)	Level of dissolved oxygen				Response to oxygen level	Reference
			P _O ₂ mm Hg	ml O ₂ /l	mg O ₂ /l	Percent saturation		
Rainbow trout larvae (<i>Salmo gairdneri</i>)	1- and 8-day old larvae	10±1	100	5.03	7.18	62.4	Elevated heart and breathing rates below this level. Bradycardia (heart rate slows) set in at lower oxygen levels	Moleten 1971
Chum salmon eggs (<i>Oncorhynchus keta</i>)	Early stage eggs	10	13.9	.7	1	8.8	Retarded devel- opment, de- formities, mor- tality, res- piratory oxygen- dependence	Alderice et al. 1957
	Pre- hatch eggs	10	>97.4	>4.9	>7.0	>61.8	Oxygen level required for normal devel- opment and non-oxygen dependent metabolism	
Chum salmon eggs (<i>Oncorhynchus keta</i>)	5-day eggs	8.0-8.2	22.2	1.17	1.67	14.07	Critical oxygen level for supply of oxygen demand and non-oxygen dependent metabolism	Wickett 1954
	85-day eggs (eyed)	3.6-4.9	>60.5 ^a	>3.5 ^a	>5.8	>28.1 ^a		

^a Calculations based on 6°C.

Table 6. (Cont'd)

Species	Size	Temperature (°C)	Level of dissolved oxygen				Response to oxygen level	Reference
			PO ₂ mm Hg	ml O ₂ /l	mg O ₂ /l	Percent saturation		
Atlantic salmon (<i>Salmo salar</i>)	Early eggs	5.5	9.62	.53	0.76	6.09	Critical oxygen level for supply of oxygen demand and non-oxygen dependent metabolism	Lindroth 1947 (from Mickett 1954)
	Near hatching	5	71.7	4.06	5.80	43.31		
Atlantic salmon (<i>Salmo salar</i>)	Hatching	17	160.8	7.0	10.0	102.67	Critical oxygen level for supply of O ₂ demand and non-oxygen dependent metabolism	Hayes et al. 1951 (from Mickett 1954)
	Eyed	10	43.14	2.17	3.1	27.36		
	Hatching	10	98.63	4.97	7.1	62.67		
Northern pike (<i>Esox lucius</i>)	From fertilization to feeding larvae	15.19	>5.18-5.66	>2.16-2.35	>3.35-3.09	>33.0	Necessary oxygen level for proper hatching, survival, and development	Siefert et al. 1973
Musichogaster (<i>Fundulus heteroclitus</i>)	Fertilization to hatching	20	101.2	3.15	4.5	64.9	Reduced hatching at this level compared to 7.5 mg/l O ₂	Voyer and Hennekey 1972
Pacific cod (<i>Gadus macrocephalus</i>)	Fertilization to hatching	3-5			>2-3		Oxygen level required for optimal hatching at 15 ‰ salinity	Alderdice and Forrester 1971

^a Estuarine fish - calculations based on salinity of 30 ‰.

The blood oxygen dissociation curve delineates the water oxygen tension where the blood ceases to be fully oxygen saturated. For optimal gas exchange, water PO_2 s preferably 20 mm Hg above that saturation point are required in trout to maintain the necessary gradient at the gills. Oxygen dissociation curves therefore provide an indication of the point where available oxygen limits or influences respiratory and circulatory functions. The shape of the blood curve and the position of the limiting O_2 tension are influenced by temperature and CO_2 such that increases in these factors elevate the PO_2 required to fully saturate the blood. Limiting oxygen tensions derived from blood curves are therefore included in Tables 1, 2 and 3. Oxygen response thresholds for circulatory and ventilatory systems are also included in these Tables.

Low oxygen levels have been shown to influence growth rate, food conversion efficiency, and feeding in some species. Cycling oxygen levels appear to adversely affect growth under laboratory conditions. As growth is an expression of the net product of metabolic functions, it is a good indicator of an overall effect of low oxygen. Adverse effects of low O_2 on growth therefore constitute a useful criterion for permissibly low oxygen levels.

Avoidance behavior has been reported for a number of species in response to low oxygen although reports of the O_2 thresholds at which this behavior is initiated vary considerably. Observed behavior patterns at low O_2 concentrations include increased activity, poor feeding behavior, and altered phototaxis. Avoidance behavior is likely a useful protective mechanism which enhances the survival potential of some species. Behavioral responses to low oxygen are summarized in subsequent tables.

It is apparent that low oxygen in the presence of toxicants enhances the lethal effect of those toxicants on some fish. Low oxygen levels producing metabolic stress could lower the ability of fish to resist toxicants as well as increase toxicant uptake rate via elevated ventilatory water flow. For these reasons, the need for sound scientific dissolved oxygen criteria should be obvious, especially in geographical areas polluted by discharges toxic to fish.

Some fish show an ability to acclimate to lowered ambient oxygen. However, the degree of advantage thus gained is not clear. Acclimation can enhance blood oxygen capacity and oxygen utilization but may not aid active swimming performance. This acclimation phenomenon may be useful to fish

subjected to gradual reductions in oxygen levels but would be of little advantage when encountering reduced oxygen levels for the first time, especially if the oxygen depression is severe. For these reasons, the application of acclimation phenomena to water oxygen criteria for fish protection has not been attempted, and can only be considered as a possible safety factor enhancing the fish's resistance to low oxygen.

Developing fish eggs and larvae show a number of responses to low oxygen including respiratory dependence, retarded growth, reduced yolk sac absorption, developmental deformities, and mortality. As development proceeds, the oxygen requirements of both eggs and larvae increase. Trout larvae exhibit circulatory and respiratory effects of low oxygen. Most data on the effects of low oxygen on fish eggs and larvae are confined to freshwater species, particularly salmonids, and there is little information for marine eggs and larvae.

OXYGEN REQUIREMENTS OF AQUATIC INVERTEBRATES - SUMMARY AND CONCLUSIONS

It is obvious from the discussion in Part B that a great range of tolerances, responses, and requirements for oxygen exist amongst aquatic invertebrates. Separate aquatic communities are also likely to differ in sensitivity to oxygen; a range of susceptibility to low O_2 is often found amongst the individuals of a community. Oxygen tolerance tends to be correlated with habitat, so that individuals normally living in well-oxygenated water are less tolerant of low dissolved oxygen than those encountering it periodically. Furthermore, there is some evidence that oxygen-dependent respiration may apply to the oxygen uptake relations of communities as well as to individuals.

Difficulty is encountered in determining safe levels of dissolved oxygen for aquatic invertebrates because of (i) the wide range of responses reported, (ii) the ability of many organisms to inhabit low oxygen regimes and obtain energy anaerobically, and (iii) a lack of understanding of the physiological effects of low O_2 . Survival in continuous levels of low oxygen depends on the ability to produce energy continuously anaerobically, or the capacity to extract oxygen from an environment low in oxygen. Also, the ability of organisms to cope with oscillating oxygen levels is very poorly known or understood. Obviously, the tolerance of the species involved and the duration of a low oxygen condition are of prime importance to survival. Utilization of anaerobic metabolism could satisfy the

energy needs of many aquatic invertebrates for long periods, particularly the smaller, sluggish forms with a typically low oxygen demand. The larger, more active forms are likely to be more affected by low O_2 and thus may be the most sensitive members of the community. Hence, a change from an adequate oxygen regime to one of relative oxygen scarcity may result in loss of the more sensitive organisms and a restructuring of the community. New species, tolerant to low oxygen, could move into the community; those already present in the community could become more numerous and replace the intolerant species. Alternatively, no replacement could take place, leading to a net reduction in biomass and/or alteration of the species composition of the community.

In conclusion, and on a commonsense basis alone, it seems likely that any depression of natural oxygen conditions can result in a change in an aquatic invertebrate community. The severity of this change will be related to the species composition, the species sensitivity to low oxygen, the degree of oxygen depression, and other factors acting on the community, such as temperature. Whether a change in an invertebrate community is necessarily bad from an ecological point of view may be very difficult to determine. It may be that a change from one type of community to another may not be necessarily deleterious. On the other hand, if major food chain constituents drop out, the change could be considered deleterious.

Insufficient evidence exists presently to formulate definite dissolved oxygen criteria concerning aquatic invertebrate communities. However, a reasonable basis will probably be assured by following the recommendations for fish populations given here, particularly since many invertebrates are able to temporarily withstand periods of low oxygen. It must be remembered, however, that any change in dissolved oxygen will likely affect invertebrate communities in some way. Ideally, we need a good knowledge of community structure in areas threatened by pollution so that important sensitive species are identified. In addition, knowledge of the seasonal oxygen minima for specific areas is required to identify periods when further oxygen depression poses a hazard to aquatic life.

OXYGEN CRITERIA FOR CANADIAN AQUATIC LIFE

Owing to the fact that oxygen levels often fluctuate in natural waters, the assessment of harm commitment was based on minimum oxygen levels in a body of water seasonally (fall, winter, spring, summer) at the seasonal temperature maximum.

These levels are presented in Table 5 and are expressed in terms of percentage saturation. Percentage saturation was chosen because it encompasses the concept of both oxygen content and partial pressure at various temperatures (see Part B of this report). In addition, it is easily understood, is directly measurable on many instruments, and can be converted easily to oxygen content or partial pressure. The criteria are graphically presented in Figs. 1A and 1B. It is stressed that these criteria are tentative and should be subject to revision as new knowledge becomes available.

Using the rationale and statistical procedures outlined in Part B, oxygen criteria were developed which represent three levels of harm (or risk) commitment concerning aquatic life:

Level A - this level represents more or less ideal conditions (i.e. little or no foreseeable harm) and permits little depression of oxygen from full saturation. It represents a level that assures a high degree of safeguard for very important stocks in prime areas.

Level B - at this level some degree of risk (i.e. possibility of moderate harm) to a portion of a fish population exists if the oxygen minimum period is prolonged beyond a few hours.

Level C - at this level a large portion of a given fish population or fish community may be affected by low oxygen. This deleterious effect may be severe (i.e. possibility of severe harm), especially if the oxygen minimum is prolonged beyond a very few hours.

RECEIVING WATER CONSIDERATIONS

Dissolved oxygen levels in both fresh- and saltwater bodies show considerable variation with location, season, depth, photosynthetic activity, respiration, organic decay processes, and atmospheric exchange. The natural condition is frequently one of change and the impact of man-made influences will vary in accordance with the above factors. Caution is therefore essential in the realistic application of oxygen criteria so that natural variations in oxygen levels can be considered. For this reason the physical characteristics of the receiving water in question must be understood. Only when knowledge of the naturally existing oxygen regime and temperature distribution in a water body are understood can criteria be sensibly

Table 5. Oxygen criteria^a for assessment of harm in various freshwater and marine fish groups.

Group	Harm commitment level	Percentage saturation at each temperature (°C)					
		0	5	10	15	20	25
Freshwater mixed fish population, including some salmonids	A	69	70	70	71	79	87
	B	54	54	54	54	57	63
	C	38	38	38	38	39	39
Freshwater mixed fish population with no salmonids	A	60	60	60	60	60	66
	B	47	47	47	47	47	48
	C	35	35	35	35	35	36
Primarily freshwater salmonid population (including steelhead)	A	76	76	76	76	85	93
	B	57	57	57	59	65	72
	C	38	38	38	42	46	51
Salmonid larvae and mature eggs of salmonids	A	98	98	98	98	100	100
	B	76	76	76	79	87	95
	C	54	54	57	64	71	78
Marine, non-anadromous species	A	88	88	95	100	100	100
	B	69	69	74	82	90	98
	C	50	51	51	55	60	65
Anadromous marine species, including salmonids	A	100	100	100	100	100	100
	B	79	79	79	79	87	94
	C	57	57	57	57	57	58

^a These criteria are defined as oxygen minima in percentage saturation allowable at seasonal temperature maxima. Three levels of harm commitment are given (A, B and C), to allow for flexibility of application. Level A provides the highest degree of protection, level C provides the lowest.

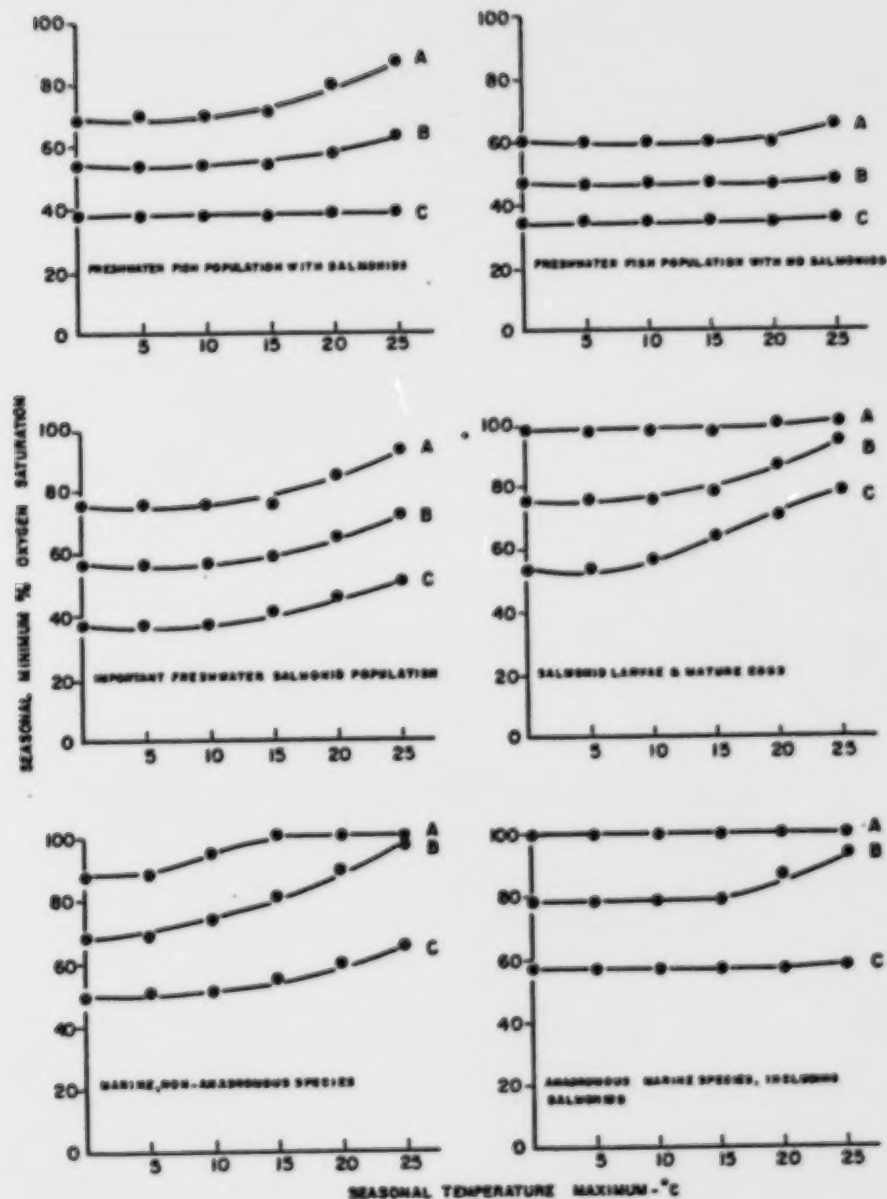


Fig. 1-A. Oxygen criteria, expressed as seasonal minima in percent saturation, at various seasonal temperature maxima. Three levels of harm commitment -- A, B and C -- are given as defined in the text. Values used in derivation of the criteria are summarized in Table 5.

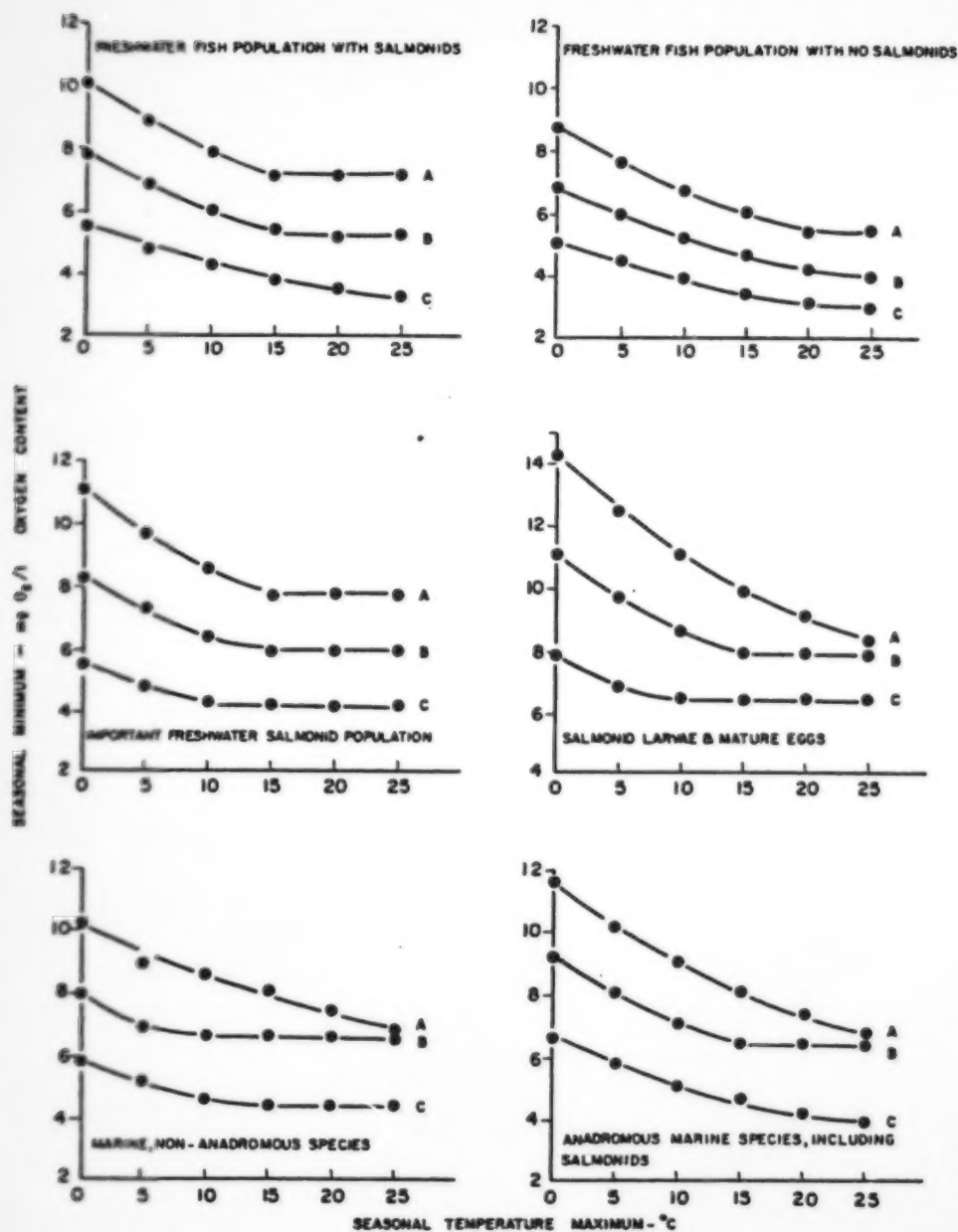


Fig. 1-B. Oxygen criteria, expressed as oxygen minima in mg O₂/l (ppm), at various seasonal temperature maxima. Three levels of harm commitment -- A, B and C -- are given as defined in the text. These values were calculated from the percentage saturation values illustrated in Fig. 1-A and summarized in Table 5.

utilized. Careful study of each area subject to criteria application is therefore warranted.

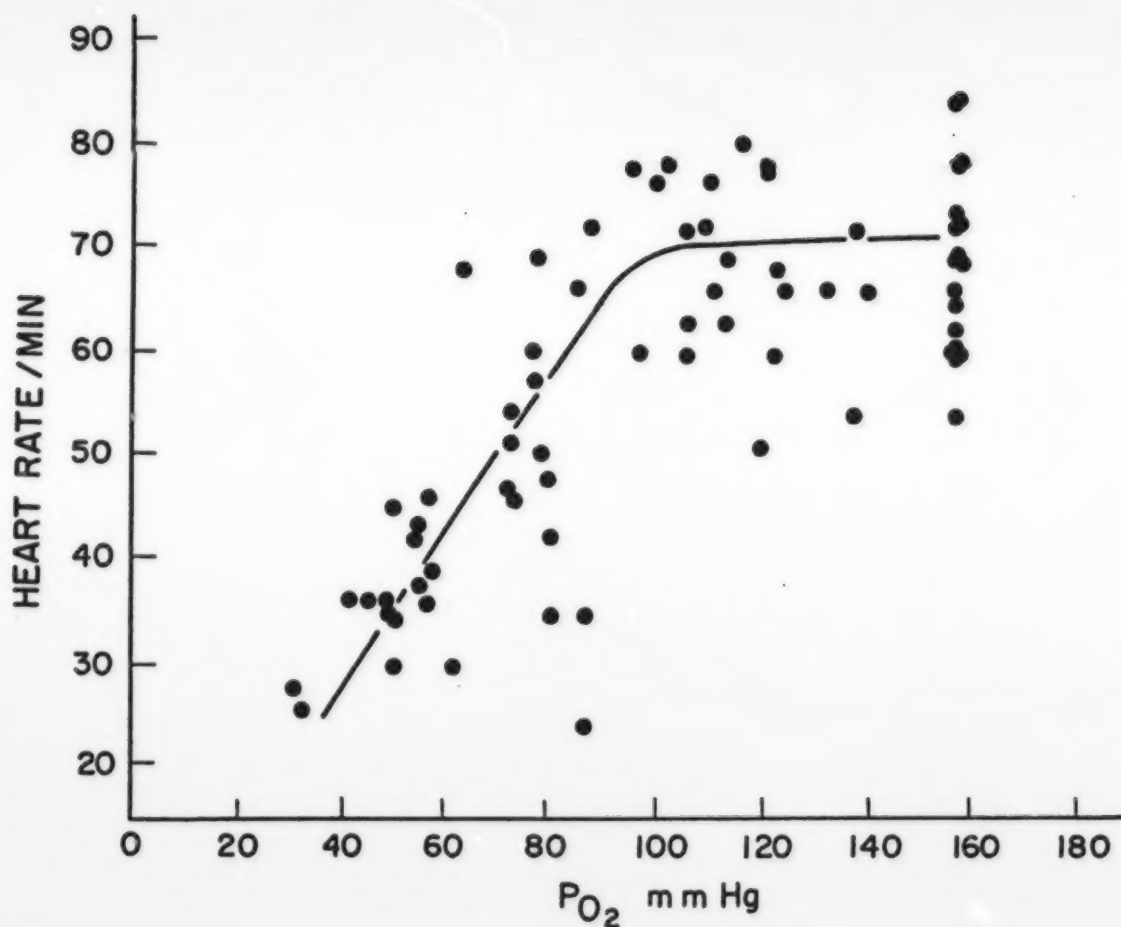


Fig. 5. The onset of bradycardia (slowing of heart beat rate) in rainbow trout in response to water oxygen tension. The solid line was fitted following a statistical analysis of the data. (From Randall and Smith (1967): *Physiol. Zool.* 40.)

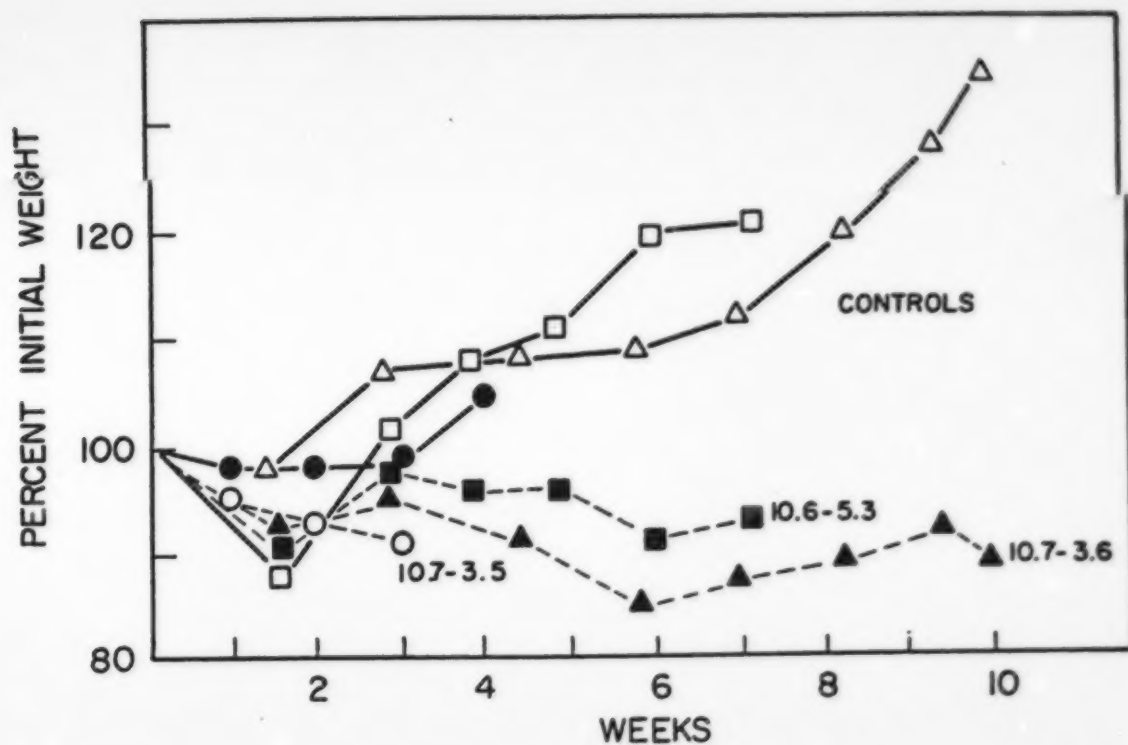


Fig. 6. Growth rate in yearling eastern Brook trout (*Salvelinus fontinalis*) in constant high levels (solid lines are controls) and various daily fluctuating levels (broken lines) of oxygen (O_2 range in mg O_2/l). (In Fry (1970 Fish Physiology, Vol. VI, Academic Press Inc.)

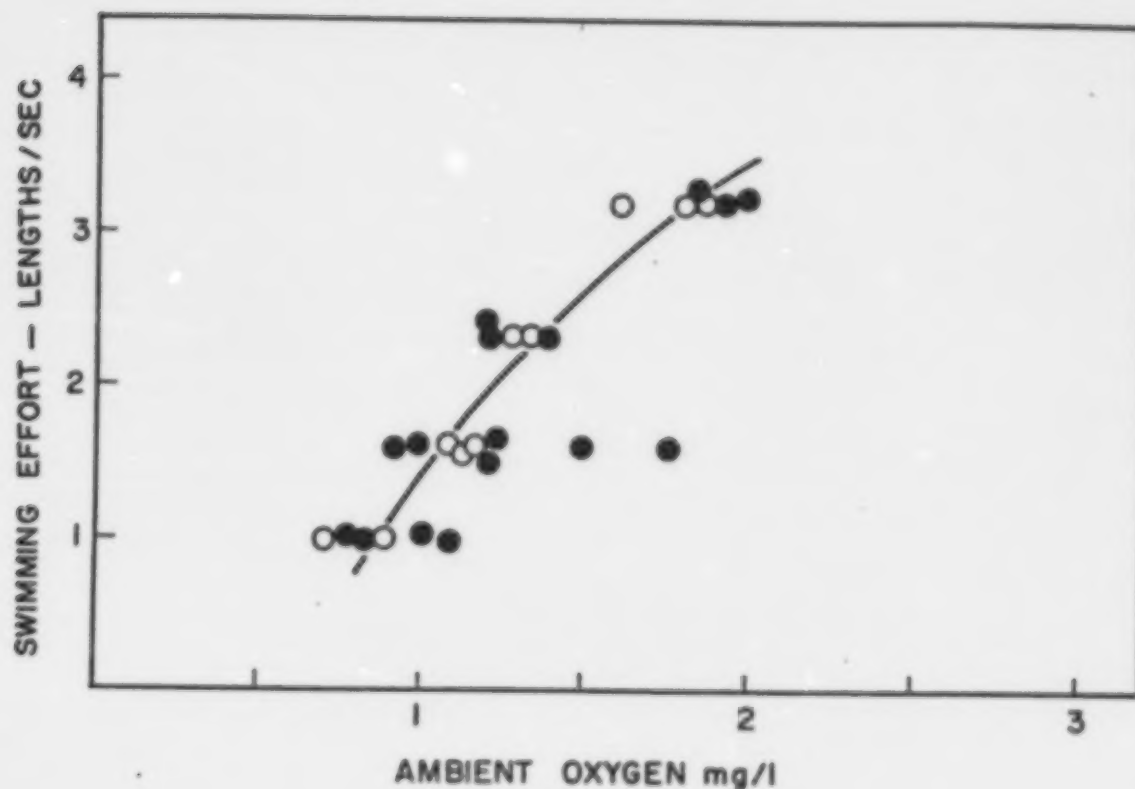


Fig. 7. Swimming ability vs. oxygen availability in goldfish. Open circles denote fish acclimated to air-saturation O_2 levels; closed circles indicate fish acclimated to 15% oxygen saturation. Acclimation to low oxygen did not appear to enhance swimming ability in low oxygen water under these conditions. (From Kutty (1968b), Can. J. Zool. 46.)

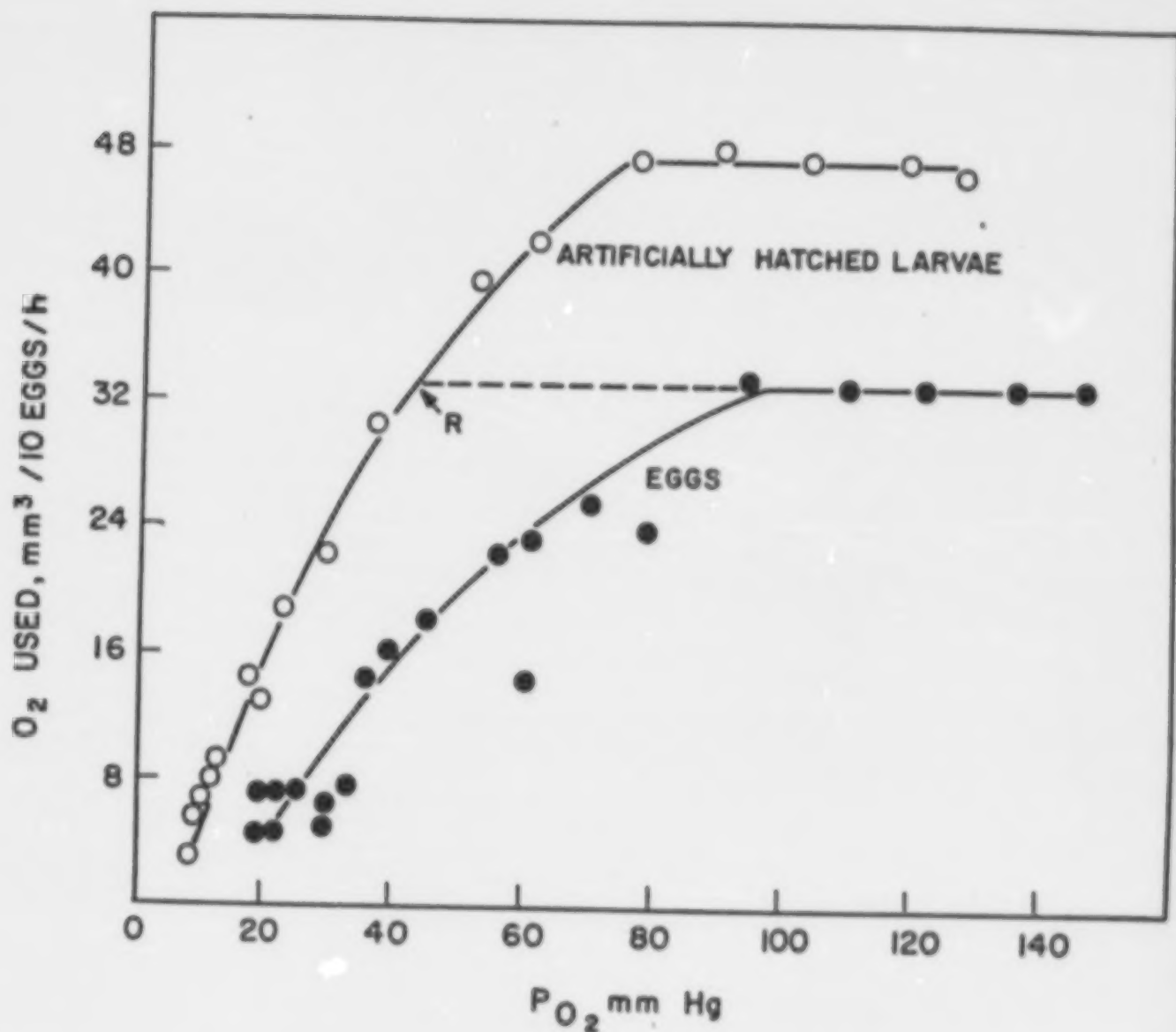


Fig. 8. Oxygen uptake rates in eggs and larvae of Atlantic salmon (*Salmo salar*) at 10°C, illustrating respiratory dependence and the influence of the egg capsule. (In Fry (1957), after Hayes et al. 1951.)

Level A - This level is one standard deviation above the mean average incipient oxygen response level for the group. The rationale is that few members of a fish population or fish community will likely exhibit effects of low oxygen at or above this level. Level A represents more or less ideal conditions and permits little depression of oxygen from full saturation. It represents a level that assures a high degree of safeguard for very important fish stocks in prime areas.

Level B - This level represents the oxygen value where the average member of a species in a fish community starts to exhibit symptoms of oxygen distress. These values are derived from the class mean averages from Table 12. Some degree of risk to a portion of fish populations exists at this level if the period of exposure to the minimum oxygen level is prolonged beyond a few hours.

Level C - At this level, a large portion of a given fish population or fish community may be affected by low oxygen. This deleterious effect may be severe, especially if the oxygen minimum is prolonged beyond a very few hours. The values are one standard deviation below the B level (or class average) for the group.

The use of standard deviations to estimate harm commitment is based on the statistical concept that in normally distributed data approximately 68% of the values lie within ± 1 standard deviation of the mean. Thus, the recommended levels span the range of responses that include both sensitive and insensitive animals.^a Analysis of the data for the freshwater fish group, including salmonids, indicates that these data are normally distributed about the mean and yield a typical cumulative frequency curve about the mean (Fig. 23).

^a A weaker form of these criteria could be adopted by setting the value of the A or B level as the average 24-hour O_2 value and the minimum O_2 concentration over any 24 hours equal to the next lower criteria level. For example, the value of A would represent the average 24-hour O_2 level and at no time should it be allowed to fall below the value of B. Adoption of this scheme could risk serious damage to fish populations at level B. Objections to the use of average values are discussed in Warren et al. (1973) and on page 88 of this report.

RELATIONSHIP OF PRESENT CRITERIA TO OTHER DOCUMENTS

In conclusion, it would appear that the oxygen criteria formulated in this report, and derived specifically for Canadian aquatic life, incorporate a number of considerations identified as critical in other oxygen criteria documents. The herein-presented criteria include the concept of seasonal oxygen minima, allow consideration of temperature, and contain three levels for the assessment of harm commitment. Level A provides a high safeguard for very important aquatic populations; with level B, there is some possibility of moderate risk to aquatic organisms because it allows some degree of oxygen depression; with level C, it is possible that a large portion of a given fish population or fish community may be severely affected by low oxygen, especially on a "chronic exposure" basis.

These criteria, unlike most others, present oxygen levels as percentage saturation (Fig. 1). This was done partly because the concept is easily understood and can be assessed conveniently. In addition, the criteria, expressed as percentage saturation, incorporate both the necessary oxygen content and partial pressure essential for fish respiration over a range of temperatures. The values can be easily converted to other units such as mg O₂/l.

Unlike other criteria, the present oxygen criteria include consideration of marine fish, based on actual data. These data are admittedly somewhat scanty; thus, there is a need for more extensive data on all aspects of pollution research with marine fish.

Oxygen requirements for the assessment of harm to aquatic invertebrates have not been specifically proposed due to the current lack of knowledge on the subject. For aquatic invertebrates, adoption of the criteria relating to fish populations is recommended, for reasons given in this report. Much more work is needed in this particular area to elucidate the effects of low oxygen on invertebrate communities and ecosystems, especially those in the sea.

The criteria presented in this report are tentative and subject to revision as new knowledge becomes available.



ANNEX B:

US EPA QUALITY CRITERIA FOR WATER QUALITY





United States
Environmental Protection
Agency

Office of Water
Regulations and Standards
Washington, DC 20460

May 1, 1986

Water

EPA 440/5-86-001

QUALITY CRITERIA for WATER 1986





DISSOLVED OXYGENNATIONAL CRITERIA:

The national criteria for ambient dissolved oxygen concentrations for the protection of freshwater aquatic life are presented in Table 1. The criteria are derived from the production impairment estimates which are based primarily upon growth data and information on temperature, disease, and pollutant stresses. The average dissolved oxygen concentrations selected are values 0.5 mg/L above the slight production impairment values and represent values between no production impairment and slight production impairment. Each criterion may thus be viewed as an estimate of the threshold concentration below which detrimental effects are expected.

Criteria for coldwater fish are intended to apply to waters containing a population of one or more species in the family Salmonidae (Bailey et al., 1970) or to waters containing other coldwater or coolwater fish deemed by the user to be closer to salmonids in sensitivity than to most warmwater species. Although the acute lethal limit for salmonids is at or below 3 mg/L, the coldwater minimum has been established at 4 mg/L because a significant proportion of the insect species common to salmonid habitats are less tolerant of acute exposures to low dissolved oxygen than are salmonids. Some coolwater species may require more protection than that afforded by the other life stage criteria for warmwater fish and it may be desirable to protect sensitive coolwater species with the coldwater criteria. Many states have more stringent dissolved oxygen standards for cooler waters, waters that contain either

salmonids, nonsalmonid coolwater fish, or the sensitive centrarchid, the smallmouth bass. The warmwater criteria are necessary to protect early life stages of warmwater fish as sensitive as channel catfish and to protect other life stages of fish as sensitive as largemouth bass. Criteria for early life stages are intended to apply only where and when these stages occur. These criteria represent dissolved oxygen concentrations which EPA believes provide a reasonable and adequate degree of protection for freshwater aquatic life.

The criteria do not represent assured no-effect levels. However, because the criteria represent worst case conditions (i.e. for wasteload allocation and waste treatment plant design), conditions will be better than the criteria nearly all of the time at most sites. In situations where criteria conditions are just maintained for considerable periods the proposed criteria represent some risk of production impairment. This impairment would depend on innumerable other factors. If slight production impairment or a small but undefinable risk of moderate impairment is unacceptable, then one should use the "no production impairment" values given in the document as means and the "slight production impairment" values as minima. The table which presents these concentrations is reproduced here as table 2.

The criteria do represent dissolved oxygen concentrations believed to protect the more sensitive populations of organisms against potentially damaging production impairment. The dissolved oxygen concentrations in the criteria are intended to be protective at typically high seasonal environmental temperatures for the appropriate taxonomic and life stage classi-

Table 1. Water quality criteria for ambient dissolved oxygen concentration.

	<u>Coldwater Criteria</u>		<u>Warmwater Criteria</u>	
	Early Life Stages ^{1,2}	Other Life Stages	Early Life Stages ²	Other Life Stages
30 Day Mean	NA ³	6.5	NA	5.5
7 Day Mean	9.5 (6.5)	NA	6.0	NA
7 Day Mean Minimum	NA	5.0	NA	4.0
1 Day Minimum ^{4,5}	8.0 (5.0)	4.0	5.0	3.0

- ¹ These are water column concentrations recommended to achieve the required intergravel dissolved oxygen concentrations shown in parentheses. The 3 mg/L differential is discussed in the criteria document. For species that have early life stages exposed directly to the water column, the figures in parentheses apply.
- ² Includes all embryonic and larval stages and all juvenile forms to 30-days following hatching.
- ³ NA (not applicable).
- ⁴ For highly manipulatable discharges, further restrictions apply (see page 37)
- ⁵ All minima should be considered as instantaneous concentrations to be achieved at all times.

fications, temperatures which are often higher than those used in the research from which the criteria were generated, especially for other than early life stages.

Where natural conditions alone create dissolved oxygen concentrations less than 110 percent of the applicable criteria means or minima or both, the minimum acceptable concentration is

90 percent of the natural concentration. These values are similar to those presented graphically by Doudoroff and Shumway (1970) and those calculated from Water Quality Criteria 1972 (NAS/NAE, 1973). Absolutely no anthropogenic dissolved oxygen depression in the potentially lethal area below the 1-day minima should be allowed unless special care is taken to ascertain the tolerance of resident species to low dissolved oxygen.

If daily cycles of dissolved oxygen are essentially sinusoidal, a reasonable daily average is calculated from the day's high and low dissolved oxygen values. A time-weighted average may be required if the dissolved oxygen cycles are decidedly non-sinusoidal. Determining the magnitude of daily dissolved oxygen cycles requires at least two appropriately timed measurements daily, and characterizing the shape of the cycle requires several more appropriately spaced measurements.

Once a series of daily mean dissolved oxygen concentrations are calculated, an average of these daily means can be calculated (Table 3). For embryonic, larval, and early life stages, the averaging period should not exceed 7 days. This short time is needed to adequately protect these often short duration, most sensitive life stages. Other life stages can probably be adequately protected by 30-day averages. Regardless of the averaging period, the average should be considered a moving average rather than a calendar-week or calendar-month average.

Table 2. Dissolved Oxygen Concentrations (mg/L) Versus Quantitative Level of Effect.

1. Salmonid Waters

a. Embryo and Larval Stages

No Production Impairment	= 11* (8)
Slight Production Impairment	= 9* (6)
Moderate Production Impairment	= 8* (5)
Severe Production Impairment	= 7* (4)
Limit to Avoid Acute Mortality	= 6* (3)

(* Note: These are water column concentrations recommended to achieve the required intergravel dissolved oxygen concentrations shown in parentheses. The 3 mg/L difference is discussed in the criteria document.)

b. Other Life Stages

No Production Impairment	= 8
light Production Impairment	= 6
Moderate Production Impairment	= 5
Severe Production Impairment	= 4
Limit to Avoid Acute Mortality	= 3

2. Nonsalmonid Waters

a. Early Life Stages

No Production Impairment	= 6.5
Slight Production Impairment	= 5.5
Moderate Production Impairment	= 5
Severe Production Impairment	= 4.5
Limit to Avoid Acute Mortality	= 4

b. Other Life Stages

No Production Impairment	= 6
Slight Production Impairment	= 5
Moderate Production Impairment	= 4
Severe Production Impairment	= 3.5
Limit to Avoid Acute Mortality	= 3

3. Invertebrates

No Production Impairment	= 8
Some Production Impairment	= 5
Acute Mortality Limit	= 4

Table 3. Sample calculations for determining daily means and 7-day mean dissolved oxygen concentrations (30-day averages are calculated in a similar fashion using 30 days data).

<u>Dissolved Oxygen (mg/L)</u>			
Day	Daily Max.	Daily Min.	Daily Mean
1	9.0	7.0	8.0
2	10.0	7.0	8.5
3	11.0	8.0	9.5 ^b
4	12.0 ^a	8.0	9.5
5	10.0	8.0	9.0
6	11.0	9.0	10.0
7	12.0 ^a	10.0	10.5 ^c
		57.0	65.0
	1-day Minimum	7.0	
	7-day Mean Minimum	8.1	
	7-day Mean		9.3

a Above air saturation concentration (assumed to be 11.0 mg/L for this example).

b $(11.0 + 8.0)2$.

c $(11.0 + 10.0)2$.

The criteria have been established on the basis that the maximum dissolved oxygen value actually used in calculating any daily mean should not exceed the air saturation value. This consideration is based primarily on analysis of studies of cycling dissolved oxygen and the growth of largemouth bass (Stewart et al., 1967), which indicated that high dissolved oxygen levels (> 6 mg/L) had no beneficial effect on growth.

During periodic cycles of dissolved oxygen concentrations, minima lower than acceptable constant exposure levels are tolerable so long as:

1. the average concentration attained meets or exceeds the criterion;
2. the average dissolved oxygen concentration is calculated as recommended in Table 3; and
3. the minima are not unduly stressful and clearly are not lethal.

A daily minimum has been included to make certain that no acute mortality of sensitive species occurs as a result of lack of oxygen. Because repeated exposure to dissolved oxygen concentrations at or near the acute lethal threshold will be stressful and because stress can indirectly produce mortality or other adverse effects (e.g., through disease), the criteria are designed to prevent significant episodes of continuous or regularly recurring exposures to dissolved oxygen concentrations at or near the lethal threshold. This protection has been achieved by setting the daily minimum for early life stages at the subacute lethality threshold, by the use of a 7-day averaging period for early life stages, by stipulating a 7-day mean minimum value for other life stages, and by recommending additional limits for manipulatable discharges.

The previous EPA criterion for dissolved oxygen published in Quality Criteria for Water (USEPA, 1976) was a minimum of 5 mg/L (usually applied as a 7Q10) which is similar to the current criterion minimum except for other life stages of warmwater fish which now allows a 7-day mean minimum of 4 mg/L. The new criteria are similar to those contained in the 1968 "Green Book" of the Federal Water Pollution Control Federation (FWPCA, 1968).

A. The Criteria and Monitoring and Design Conditions

The acceptable mean concentrations should be attained most of the time, but some deviation below these values would probably not cause significant harm. Deviations below the mean will probably be serially correlated and hence apt to occur on consecutive days. The significance of deviations below the mean will depend on whether they occur continuously or in daily cycles, the former being more adverse than the latter. Current knowledge regarding such deviations is limited primarily to laboratory growth experiments and by extrapolation to other activity-related phenomena.

Under conditions where large daily cycles of dissolved oxygen occur, it is possible to meet the criteria mean values and consistently violate the mean minimum criteria. Under these conditions the mean minimum criteria will clearly be the limiting regulation unless alternatives such as nutrient control can dampen the daily cycles.

The significance of conditions which fail to meet the recommended dissolved oxygen criteria depend largely upon five factors: (1) the duration of the event; (2) the magnitude of the dissolved oxygen depression; (3) the frequency of recurrence; (4) the proportional area of the site failing to meet the criteria, and (5) the biological significance of the site where the event occurs. Evaluation of an event's significance must be largely case- and site-specific. Common sense would dictate that the magnitude of the depression would be the single most important factor in general, especially if the acute value is violated. A

logical extension of these considerations is that the event must be considered in the context of the level of resolution of the monitoring or modeling effort. Evaluating the extent, duration, and magnitude of an event must be a function of the spatial and temporal frequency of the data. Thus, a single deviation below the criterion takes on considerably less significance where continuous monitoring occurs than where sampling is comprised of once-a-week grab samples. This is so because based on continuous monitoring the event is provably small, but with the much less frequent sampling the event is not provably small and can be considerably worse than indicated by the sample. The frequency of recurrence is of considerable interest to those modeling dissolved oxygen concentrations because the return period, or period between recurrences, is a primary modeling consideration contingent upon probabilities of receiving water volumes, waste loads, temperatures, etc. It should be apparent that return period cannot be isolated from the other four factors discussed above. Ultimately, the question of return period may be decided on a site-specific basis taking into account the other factors (duration, magnitude, areal extent, and biological significance) mentioned above. Future studies of temporal patterns of dissolved oxygen concentrations, both within and between years, must be conducted to provide a better basis for selection of the appropriate return period.

In conducting wasteload allocation and treatment plant design computations, the choice of temperature in the models will be important. Probably the best option would be to use temperatures consistent with those expected in the receiving water over the

critical dissolved oxygen period for the biota.

B. The Criteria and Manipulatable Discharges

If daily minimum DOs are perfectly serially correlated, i.e., if the annual lowest daily minimum dissolved oxygen concentration is adjacent in time to the next lower daily minimum dissolved oxygen concentration and one of these two minima is adjacent to the third lowest daily minimum dissolved oxygen concentration, etc., then in order to meet the 7-day mean minimum criterion it is unlikely that there will be more than three or four consecutive daily minimum values below the acceptable 7-day mean minimum. Unless the dissolved oxygen pattern is extremely erratic, it is also unlikely that the lowest dissolved oxygen concentration will be appreciably below the acceptable 7-day mean minimum or that daily minimum values below the 7-day mean minimum will occur in more than one or two weeks each year. For some discharges, the distribution of dissolved oxygen concentrations can be manipulated to varying degrees. Applying the daily minimum to manipulatable discharges would allow repeated weekly cycles of minimum acutely acceptable dissolved oxygen values, a condition of unacceptable stress and possible adverse biological effect. For this reason, the application of the one day minimum criterion to manipulatable discharges must limit either the frequency of occurrence of values below the acceptable 7-day mean minimum or must impose further limits on the extent of excursions below the 7-day mean minimum. For such controlled discharges, it is recommended that the occurrence of daily minima below the acceptable 7-day mean

minimum be limited to 3 weeks per year or that the acceptable one-day minimum be increased to 4.5 mg/L for coldwater fish and 3.5 mg/L for warmwater fish. Such decisions could be site-specific based upon the extent of control and serial correlation.



ANNEX C:

DISSOLVED OXYGEN GUIDELINES
CANADIAN WATER QUALITY GUIDELINES

Table 3-6. Guidelines for Dissolved Oxygen

Categories of biota	Dissolved oxygen concentration (mg·L ⁻¹)	
	Early life stages	Other life stages
Warm-water	8	5
Cold-water	9.5 (6.5) ¹	6.5

¹ Interstitial water of the gravel.

Source: Modified from U.S. EPA 1986.

Table 3-7. Minimum Dissolved Oxygen Concentrations at Different Levels of Fishery Protection

Level of production impairment	Dissolved oxygen concentration (mg·L ⁻¹)			
	Salmonid waters ¹		Nonsalmonid waters	
	Embryo larva	Other stages	Embryo larva	Other stages
None	11 (8)	8	6.5	6
Slight	9 (6)	6	5.5	5
Moderate	8 (5)	5	5	4
Severe	7 (4)	4	4.5	3.5
Acute mortality	6 (3)	3	4	3

¹ The intergravel dissolved oxygen concentrations are shown in parentheses (a difference of 3 mg·L⁻¹ between the water column and the intergravel concentrations has been assumed).

Source: U.S. EPA 1986.

Freshwater plants show a wide range of sensitivities to cyanide. The most sensitive was the green alga (*Scenedesmus quadricauda*); incipient inhibition of this alga occurred at a cyanide concentration of 30 µg·L⁻¹ (Bringmann and Kuhn 1977, 1978b). Adverse effects on plants are unlikely at concentrations which are not chronically toxic to fish species.

Biomagnification of cyanide has not been demonstrated (U.S. EPA 1985g).

The numerical limit of 5.0 µg·L⁻¹, proposed by the Ontario Ministry of the Environment (1984) and IJC (1978a), is recommended as a guideline because more recent literature supports this value. The measurement of free cyanide is recommended because it is the primary toxic form and the form measured in toxicity tests; however, sample preservation and analytical problems may make monitoring for free cyanide unreliable, particularly in waters affected by mine wastes. In such cases, the measurement of weak-acid-dissociable cyanide and total cyanide is tentatively recommended. Where metalocyanide complexes, especially iron-cyanide complexes, may be present, the measurement of total cyanide is recommended.

3.2.1.10 Dissolved Oxygen

3.2.1.10.1 Guideline

The concentration of dissolved oxygen should not be less than those concentrations shown in Table 3-6. When applying these guidelines natural variations in dissolved oxygen concentrations must be taken into account.

Until more data are available, the dissolved oxygen concentration in the interstitial water of the gravel should be considered to be at least 3 mg·L⁻¹ lower than the oxygen concentra-

Table 3-8. Numerical Limits for Ambient Dissolved Oxygen as Proposed by U.S. EPA (1986)

Description	Ambient dissolved oxygen limits (mg·L ⁻¹)			
	Cold water		Warm water	
	Early life stages	Other life stages	Early life stages	Other life stages
30-d mean	NA ¹	6.5	NA	5.5
7-d mean	9.5 (6.5)	NA	6.0	NA
Minimum	NA	5.0	NA	4.0
1-d minimum	8.0 (5.0)	4.0	5.0	3.0

¹ NA = not applicable.

Source: U.S. EPA 1986.

tion in the overlying water (U.S. EPA 1986). In salmonid spawning habitats, the water column concentration of dissolved oxygen should, therefore, be 9.5 mg·L⁻¹, so that the interstitial concentration (shown in parentheses) is 6.5 mg·L⁻¹. The guideline for the early life stages applies from spawning through to 30 d after hatching. In eutrophic waters, minimum concentrations may occur at night (or dawn) because of diurnal cycling.

3.2.1.10.2 Summary of Documents

The U.S. EPA (1976) recommended a minimum concentration of 5.0 mg·L⁻¹ dissolved oxygen to maintain good fish populations. The numerical limit for salmonid spawning beds was a minimum of 5.0 mg·L⁻¹ in the interstitial water of the gravel.

The U.S. EPA published new criteria for dissolved oxygen in 1986 (U.S. EPA 1986). This document (U.S. EPA 1986) contains a thorough updating of the literature; it separates cold-water from warm-water species, and it separates early life stages from other stages. The document estimates four levels of impairment for different species and stages (Table 3-7). The proposed numerical limits include mean (7- and 30-d) and minimum (7- and 1-d) values (Table 3-8).

Davis (1975) differentiated between fish populations, temperatures and levels of risk. Dissolved oxygen concentrations were expressed as percent saturation. The limits recommended by Davis (1975), which emphasize the Canadian environment, form the foundation for provincial values for aquatic life prepared since 1975 (Ontario Ministry of the Environment 1979; Williamson 1983). Table 3-9 summarizes the recommended limits for the most common species groups and an intermediate degree of risk. Larvae and eggs of salmonids require higher levels of saturation (76-95%) than those shown for salmonid populations generally.

The IJC stated that in the connecting channels and in the upper lakes of the Great Lakes, the dissolved oxygen concentration should not be less than 8 mg·L⁻¹ at any time; in hypolimnetic waters, it should be not less than the concentration necessary for the support of fish life, particularly cold-water species (IJC 1978b). This remained the same as the numerical value in the 1972 agreement (IJC 1972), even though there was some discussion on recommending two levels (IJC 1980).

Because dissolved oxygen levels fluctuate naturally and the available data are limited, the EIFAC Working Party on Water Quality Criteria for European Freshwater Fish tentatively sug-

Table 3-9. Dissolved Oxygen Limits as Recommended by Davis (1975)

Temperature (°C)	Dissolved oxygen limits ¹					
	Warm-water biota		Cold-water biota		Primarily salmonids	
	% Sat.	mg·L ⁻¹	% Sat.	mg·L ⁻¹	% Sat.	mg·L ⁻¹
0	47	7	54	8	57	8
5	47	6	54	7	57	7
10	47	5	54	6	57	6
15	47	5	54	6	59	6
20	47	4	57	5	65	6
25	48	4	63	5	72	6

¹ Expressed as percent saturation.

Source: Davis 1975.

gested that for moderately tolerant freshwater species, the annual 50- and 5-percentile dissolved oxygen concentrations should be greater than 5 and 2 mg·L⁻¹, respectively, and for salmonids the 50- and 5-percentile concentrations should be 9 and 5 mg·L⁻¹, respectively (Alabaster and Lloyd 1982).

The preceding dissolved oxygen limits are minimum values; numerical limits for maximum (supersaturation) levels are not included herein, although supersaturation may cause gas bubble trauma in fish.

3.2.1.10.3 Rationale

The dissolved oxygen requirements of cold-water fish are assumed to be similar to requirements for salmonids, although there are only a few data to support this. Smelts, pikes and sculpins are at least as sensitive. Walleye and smallmouth bass are also moderately sensitive. When no such fish species are present, the warm-water guidelines apply.

Data on the tolerance for low dissolved oxygen concentrations are available for only a few species of nonsalmonid fish. Larval and juvenile nonsalmonids are frequently more sensitive to exposures to low dissolved oxygen than are other life stages (U.S. EPA 1986).

Few appropriate data are available on the effects of low dissolved oxygen on freshwater invertebrates. If, however, all life stages of fish are protected, the invertebrate communities should also be reasonably protected, although they may not be unchanged (Davis 1975).

The combination of low dissolved oxygen and toxic chemicals may lead to stress responses in aquatic organisms. The toxicities of zinc, lead, copper, pentachlorophenol, cyanide, hydrogen sulphide and ammonia are enhanced by low dissolved oxygen.

Higher water temperatures increase the adverse effects of low dissolved oxygen on fish. Because high temperature and low dissolved oxygen commonly occur together in natural environments, the additive or synergistic effect of these two potential stresses is an important consideration. The recommended guidelines are protective at high seasonal environmental temperatures. Maintenance of adequate oxygen at high temperatures is important for fish growth, because fish normally attain high growth rates at high temperatures. Growth under fluctuating oxygen concentrations is almost always less

than growth at a constant concentration equal to the mean concentration (U.S. EPA 1986).

The recommended guidelines represent dissolved oxygen concentrations believed to protect the more sensitive populations of organisms against potentially damaging production impairment. The guidelines are derived from a condensation of U.S. EPA information which gives dissolved oxygen in mg·L⁻¹ and not as percent saturation, and states that all minima should be considered as instantaneous considerations to be achieved at all times (U.S. EPA 1986).

3.2.1.11 Iron

3.2.1.11.1 Guideline

The concentration of total iron should not exceed 0.3 mg·L⁻¹.

3.2.1.11.2 Summary of Documents

The IJC (1978a) has established a numerical limit for total iron in the Great Lakes of 0.3 mg·L⁻¹, which is the same as the limit set by the Ontario Ministry of the Environment (1984). The Manitoba limit is 1.0 mg·L⁻¹ (Williamson 1983), which is the same as the U.S. EPA (1976) recommendation. More recent criteria documents published by the U.S. EPA have not included iron.

3.2.1.11.3 Rationale

The toxicity of iron to invertebrates is variable. Acute toxicity to aquatic insects occurred at iron concentrations ranging from 0.32 to 16.0 mg·L⁻¹ (Warnick and Bell 1969). The most sensitive species was the mayfly (*Ephemera subvaria*), but it was also unusually sensitive to all metals included in the test. The safe concentration for reproduction and growth of *Gammarus minus* was less than 3.0 mg·L⁻¹ (Sykora et al. 1972). The 3-week LC₅₀ for *Daphnia magna* was 5.9 mg·L⁻¹ (Biesinger and Christensen 1972).

The fathead minnow appears to be more sensitive to iron than is brook trout. A 50% reduction in the hatchability of fathead minnow eggs occurred at an iron concentration of 1.5 mg·L⁻¹ but the hatchability of brook trout eggs was affected at 12.0 mg·L⁻¹ (Sykora et al. 1972; Smith et al. 1973). The safe concentration for exposure of brook trout (*Salvelinus fontinalis*), based on the mortality of juveniles, was between 7.5 and 12.52 mg·L⁻¹. The iron hydroxide precipitate interferes with respiration through the chorion in fish eggs, and impairs gill function by occlusion of the lamellae (Sykora et al. 1972).

Because the numerical limit established by the Province of Ontario and the IJC appears to provide adequate protection to fish (based on the limited chronic data available) and to most invertebrates, it is recommended until further data are available. A concentration of 1.0 mg·L⁻¹ appears to be too close to the EC₅₀ for the fathead minnow to offer adequate protection.

3.2.1.12 Lead

3.2.1.12.1 Guideline

The concentration of total lead should not exceed the concentrations shown in Table 3-10.

FISH EGG EMBRYONIC DEVELOPMENT AND OXYGEN

by

Earle G. Baddaloo
Standards Research and Development Branch
Alberta Environment

The importance of adequate dissolved oxygen to developing eggs deposited by fish cannot be over-emphasized. Under normal conditions, physico-chemical properties of gravel used by spawning salmonids are frequently inimical to high survival; for example, less than 10% of free swimming fry leave the eggs that were deposited by their parents (Mason 1969). Such substantially low figures under normal conditions are further reduced, or in many cases, populations are eliminated because of excessive sinks in dissolved oxygen as a result of industrial discharges.

The following are a number of concerns regarding embryonic development and low dissolved oxygen:

- Various adaptations have evolved to assist in obtaining oxygen, these are as follows:
 - Gravel deposition - salmonids;
 - Parental guarding and ventilation - Stickleback (*Gasterosteus aculeatus*);
 - Pelvic gills for oxygenating eggs in nest - Lungfish (*Lepidosiren*);
 - Oxygen and nutrients obtained from female - viviparous; and
 - Newly hatched trout produce respiratory currents using pectoral fins which also keep the body clear of silt.
- Intake of oxygen has been measured in a number of species. In the egg stage, intake is very low and variable before fertilization. Before any movement in the egg, relative values of oxygen uptake between stages and species are variable, but subsequent to movement, oxygen consumption is dominated by bursts of activity.
- Oxygen uptake might be used also to express metabolic functions. Total or general metabolism consists of two components, active metabolism (owing to activity) and basal metabolism (owing to maintenance functions).
- In salmonids, oxygen uptake falls at low ambient oxygen tensions; young stages can resist this quite well for a short time.
- Respiratory problems vary with the environment of the developing egg and larvae.
- Eggs deposited on or in substrate may act as an oxygen sink: e.g., oxygen level at the egg surface is less than that of the surroundings even in high-velocity currents.

- Sensitivity to low oxygen tensions or anoxia varies with both species and stage of development.
- Cleavage could continue in anoxic condition, possibly because requirements early in development are low and oxygen is stored in the egg, especially in the perivitelline fluid.
- Gastrulation is easily blocked by lack of oxygen, or in some cases, by respiratory poisons.
- Development could be retarded by blockage of oxidative phosphorylation.
- Lack of oxygen causes increases in abnormal pigmentation and lactic acid production, but in the short term retardation of development as a result of anoxia might be reversible (DeCiechowski 1965).
- For arctic char (*Salvelinus alpinus*), hypoxia causes increases in both ventilation and heart rate (Table 1). Prolonged exposure leads to a retardation of gill growth, particularly the proliferation of secondary lamellae (McDonald and McMahon 1977).

Table 1. Summary of gill morphometric data between hypoxic and normoxic groups.

Age (days)	Weight (mg)	Filament		Lamellae	
		No.	Surface area (mm) ²	No.	Surface area (mm) ²
38 Hypoxic	76	385*	14.7*	1221*	3.0*
Normoxic	90	462*	22.1*	2539*	6.2*
47 Hypoxic	79	433*	23.6*	2296*	7.8
Normoxic	99	554*	29.0*	3686*	9.0

* Significant differences.

Source: Summarized McDonald and McMahon (1976).

- At 15°C and 19°C, and at flows of 60 and 30 m/min (velocities about 3.3 and 1.6 cm/min) 50% oxygen saturation was sufficient for survival and development of northern pike (*Esox lucius*) embryos and larvae (Figure 1). Oxygen tensions of about 33% saturation appear inadequate for proper survival (Siefert, Spoor, and Syrett 1973).

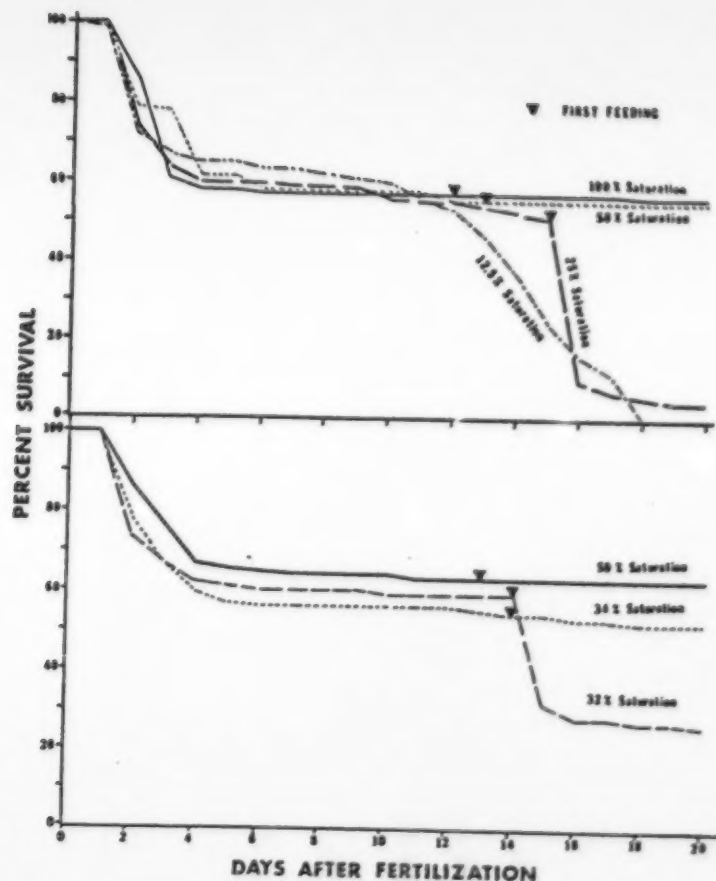


Figure 1. Percentage survival to 20 days after fertilization of northern pike (*E. lucius*) at 15°C, 60 (above) and 30 (below) mL/min water flow rates, and various dissolved oxygen concentrations.

Source: Siefert, Spoor, and Syrett (1973).

- A moderate reduction (Table 2) in survival occurred at 35% saturation of dissolved oxygen at 4°C and further significant reductions were recorded at 25% saturation at 4°C for mountain white fish (*Prosopium williamsoni*), average growth was reduced by 1.6 mm at 50% saturation at 4°C and by 3.2 mm at 35% saturation of 4°C (Siefert, Carlson, and Herman 1974).

Table 2. Time of hatching, total length and survival of mountain whitefish at the oxygen concentration and temperature indicated and flow rate of 600 mL/min.

4°C Oxygen %Sat	mg/L	Av. No. of Days to Start of Hatching	Total Length (mm)	Survival at End of Test
100	12.3	90	25.15	586
50	6.5	96.5	25.55	86
35	4.6	104	20.40	71
25	3.5	110	15.15	17
20	2.6	115	13.0	1
12.5	1.7	-	-	0
7°C				
100	11.3	60	32.8	83
50	6.0	62	27.6	84
25	3.1	71.5	-	0

Source: Taken from Siefert, Carlson and Herman (1974).

References

- DeCiechowski, J.D. 1965. The development of fish embryos in a non-aqueous medium. *Acta. Embryol. Morphol. Exptl.* 8:183-188.
- Mason, J.C. 1969. Hypoxial stress prior to emergence and competition among coho salmon fry. *J. Fish. Res. Bd. Canada* 26:63-91.
- McDonald, D.G. and B.R. McMahon. 1977. Respiratory development in arctic char *Salvelinus alpinus* under conditions of normoxia and chronic hypoxia. *Can. J. Zool.* 55:1461-1467.
- Siefert, R.E., A.R. Carlson, and L.J. Herman. 1974. Effects of reduced oxygen concentrations on the early life stages of mountain whitefish, small-mouth bass, and white bass. *The progressive fish-culturist* 36(4):186-190.
- Siefert, R.E., W.A. Spoor, and R.F. Syrett. 1973. Effects of reduced oxygen concentration on northern pike (*Esox lucius*) embryo and larvae. *J. Fish. Res. Bd. Can.* 30:849-852.

RESEARCH NEEDS BASED ON DATA GAPS¹

by
Patricia Tones
Beak Associates & Consulting Ltd.

- Methodology for conversion of guidelines to site-specific objectives.
- Salmonids are the subject of most laboratory assessments. Other species such as northern pike and whitefish that are indigenous to specific river systems should be examined.
- Extrapolation of laboratory data to field situations is difficult.

¹Main points of verbal presentation.



DISCUSSION AND SUMMARY

by
Leonard E. Lillie
Animal Sciences Division
Alberta Environmental Centre

1. INTRODUCTION

One of the benefits of a workshop is that it provides an opportunity to review some basic principles about whatever subject the workshop is intended to address--in this case, dissolved oxygen. It is easy enough in the press of daily events to concentrate on the doing of things and to lose track of why these things needed doing in the first place.

Since we are engaged in a workshop on dissolved oxygen, we have an opportunity to re-examine some basic principles about dissolved oxygen such as:

1. What is dissolved oxygen?
2. How did it get there?
3. What does it do?
4. How do we know?
5. Why do we need to know?

These are superficially simple but in fact fundamental questions. Of more direct pertinence to this workshop:

1. Why do we measure dissolved oxygen?
2. How do we measure dissolved oxygen?
3. How do we interpret the results?
4. How do we use those interpretations?

Without digressing too far from the specific objectives of the workshop or getting too academic, I would like to discuss some of these questions and then comment on and try to integrate the different presentations.

2. WHAT IS DISSOLVED OXYGEN?

Dissolved oxygen is molecular oxygen in water (or other) solution.

3. HOW DID IT GET THERE?

Before the establishment of terrestrial life, all oxygen originated as dissolved oxygen and was produced as a byproduct (actually a waste product) of photosynthetic metabolic activity of primitive

aquatic plants. This primordial oxygen eventually became adequate to enable the evolution of aquatic animal life. Sufficient oxygen was produced that it began to be passed off into the atmosphere as it then existed and eventually enough was accumulated to allow for the evolution of terrestrial life including man. At some point along the way, terrestrial plants were also established and began to contribute oxygen directly to the atmosphere. There is a certain irony to all of this. A gas which for hundreds of millions of years was a useless waste product has become essential to life as we know it.

In addition to what might be called primary production by aquatic plants, oxygen also becomes dissolved in water by the physico-chemical processes of entrainment and dissolution. This can be by direct interaction at the air/water interface but it is more usually due to some form of turbulence whereby either water is forced into air or air is forced into water. Both phases separate rapidly but a portion of the air becomes enmeshed in the molecules of the air. The first process contributes to the amount of oxygen dissolved in the water; the second contributes to the amount of water vapour in the air.

The amount of air which can be forced into and held in water solution is affected by temperature and pressure according to basic laws of physics. These basic laws of physics are directly relevant to this workshop and should neither be forgotten nor taken for granted.

Much more oxygen (or other gas) can be held in solution at high pressure than at low pressure. This phenomenon is seen each time we take the cap off a carbonated beverage. Under the reduced atmospheric pressure the carbon dioxide dissolved in the water phase of the beverage begins to form progressively larger bubbles which are then passed off into the atmosphere when their buoyancy exceeds surface conditions where the pressure exerted is normally one atmosphere and changes very little. However, it may be a factor in bodies of water at high altitude.

Much more oxygen can be held in solution at low temperature than at high temperature. This phenomenon is seen every time we boil water. Again, as the temperature rises, the amount of air (including oxygen) which can be maintained in solution is decreased and the dissolved gases begin to form small bubbles which also eventually pass off into the atmosphere. Pressure and temperature interact. Water boils at a lower temperature at higher altitudes.

While pressure is of relatively little concern under ambient conditions, temperature is a major factor in the total amount of oxygen which can be maintained in water solution and is directly pertinent to this workshop.

4. WHAT DOES IT DO?

Dissolved oxygen is the source of oxygen for all forms of aquatic animal life which function by aerobic metabolism. While the

relationship between oxygen as a solute and water as a solvent is a physico-chemical relationship, the availability of that oxygen to aquatic organisms is a physiologic relationship. It is important not to confuse or lose sight of that difference.

Under optimal conditions, oxygen dissolved in water comes in contact with the respiratory membranes of aquatic animals and a proportion of the oxygen diffuses through the respiratory membrane, into the circulatory system of that animal thus enabling the processes of cellular respiration to continue and the organism to stay alive.

While the metabolic rates and therefore, the susceptibility to oxygen deprivation of different organisms and different life stages vary, virtually all animals require a more or less continuous supply of oxygen in order to live.

5. WHY DO WE NEED TO KNOW?

The measurement of dissolved oxygen has become a major factor in assessing the health of aquatic ecosystems. Measurement of dissolved oxygen tells us two things. The first is the physical and chemical profile of the water or at least a part of that profile. In that sense when we measure dissolved oxygen, we are attempting to determine a chemical ratio and that chemical ratio is generally expressed in some kind of weight/volume relationship usually milligrams per litre (mg/L).

If the objective or purpose of measuring dissolved oxygen in water is to determine the chemical profile of the water, then that parameter tells us what we need to know. However if, as I suspect, the principal purpose of measuring dissolved oxygen in water is to determine the suitability of that body of water for the maintenance of aquatic life, then the oxygen which is dissolved oxygen in the water has to be considered from a physiological perspective.

The respiratory membrane and respiratory processes of a "water-breathing" animal such as a fish are not very different from those of an air-breathing animal such as ourselves. The respiratory membrane, whether a gill filament or an alveolus, consists of a membrane which is generally only two cells thick and which is exposed on the "outside" to the medium in which the oxygen is available and on the "inside" to the circulatory system. Oxygen moves across the membrane by simple diffusion and in relation to the partial pressure of oxygen either in the water passing over the gills or in the inspired air. If the partial pressure of oxygen in either the water or the air is insufficient (i.e., it is less than the partial pressure of oxygen in the circulating blood) then the oxygen will not diffuse across the membrane and is unavailable to the animal. This is true irrespective of the chemical concentration of oxygen.

In water therefore, it is the partial pressure of the oxygen in the water and not the chemical concentration which is the factor that makes oxygen available to fish (or other aquatic animals) and enables survival.

Partial pressure in turn is a function of percent saturation and percent saturation is a function of temperature and chemical concentration. Chemical concentration is not an unimportant factor in the process, but it is not the only factor. For example, at 25°C and at a concentration of 5 mg/L, water is 60% saturated. At 0°C, and at the same concentration, that water is only 35% saturated. At 25°C, the partial pressure generated will be more than adequate for respiration. At 0°C, that same concentration will be inadequate to provide the partial pressure required to drive the oxygen across the respiratory membrane and at that temperature aquatic animals would be in a state of oxygen deficiency.

6. OTHER FACTORS AFFECTING THE AVAILABILITY OF OXYGEN

We are all well aware of most of the factors which tend to deplete water of its oxygen content. These tend to be classified broadly under chemical and biological oxygen demand and include a wide variety of substances which "use up" the available oxygen. In essence, any substance which is introduced into water and which uses the oxygen in the water more quickly or any factor which prevents re-aeration will tend to reduce the concentration of oxygen in the water and thereby the percent saturation and the partial pressure. Factors which tend to reduce oxygen may be of natural or of anthropogenic origin. While we can usually do relatively little about the natural processes, it is the anthropogenic activities which environmental standards or guidelines seek to control. These anthropogenic activities can be classified generally as industrial, municipal, or agricultural effluents and are "elective" additions to the water system. The objective of environmental standards or guidelines is to control the introduction of these effluents into water systems so that the added effect of the effluents to the natural situation does not reduce the oxygen partial pressures below that which is needed to maintain the stability and reproductive potential of populations of aquatic organisms.

It is also important to keep in mind that dissolved oxygen is an "acute" phenomenon. While low dissolved oxygen partial pressures in water may result in the sudden death of aquatic organisms, low dissolved oxygen is not a persistent parameter in water systems. It is equally important to keep in mind that adequate dissolved oxygen (and thereby an absence of acute death in aquatic organisms) says nothing about the presence of other contaminants, particularly persistent contaminants, in the water. There is every reason to assume that the presence of such contaminants may enhance the oxygen requirements of aquatic organisms.

7. OBJECTIVES OF THE WORKSHOP

The purpose of the workshop is to review current guidelines for dissolved oxygen in Alberta and to compare those with similar objectives or guidelines in other jurisdictions and in particular to current and proposed federal guidelines. In doing so, and at the risk of redundancy, it is important to keep in mind why we need a dissolved oxygen objective or guideline and to ensure that the way the guideline is determined is appropriate to meet that objective.



APPENDIX A:

WORKSHOP AGENDA



DISSOLVED OXYGEN OBJECTIVES WORKSHOP

December 12, 1989

9:00 a.m.

Room 1239
12th Floor, Oxbridge Place
9820 - 106 Street
Edmonton, Alberta

A G E N D A *MORNING SESSIONTime

- | | |
|---------------|--|
| 9:00 - 9:08 | 1. WELCOME & INTRODUCTORY REMARKS - BRYAN KEMPER |
| 9:08 - 9:10 | 2. TECHNICAL PROGRAM (MODERATOR [WORKSHOP OBJECTIVES & FORMAT] - PAUL SHEWCHUK) |
| 9:10 - 10:00 | 2.1 Application of the CCREM Guideline for Dissolved Oxygen to a Water Quality Objective to Protect Aquatic Life - DR. PAT TONES |
| 10:00 - 10:10 | --- I N T E R M I S S I O N --- |
| 10:10 - 10:25 | 2.2 Dissolved Oxygen Objectives in Alberta (Historical Perspective) and Other Jurisdictions - PAUL SHEWCHUK |
| 10:25 - 10:45 | 2.3 Ambient Objectives: Status - DR. PERCY SIMS |
| | 2.4 Monitoring: |
| 10:45 - 11:05 | (a) Alberta Stations - Rivers and Lakes - DAVE TREW/PAT MITCHELL |
| 11:05 - 11:25 | (b) Some Aspects of Measuring Dissolved Oxygen in the the Athabasca River - LEIGH NOTON |
| 11:25 - 11:40 | 2.5 Dissolved Oxygen Guidelines - Aquatic Toxicology - DR. JIM MOORE |
| 11:40 - 1:00 | --- |

--- L U N C H ---

Courtyard Inn on 7th
10001 - 107 Street
Edmonton, AB
429-2861

AFTERNOON SESSION

2.6 Modelling Applications:

1:20 - 1:40 (a) Licensing of Industrial Plants - IAN MacKENZIE

2.7 Fisheries Protection:

1:40 - 2:00 (a) Fisheries Habitat Protection Guidelines
- Guideline No. 6 - ALLAN LOCKE

2:00 - 2:20 (b) Timing Constraints on Fisheries Based on Guideline
No. 6 - PAUL SHEWCHUK

2:20 - 2:30 --- I N T E R M I S S I O N ---

2.8 Fisheries Physiological Responses:

2:30 - 2:50 (a) Excerpts from National Research Council Report #13
(J.C. Davis Report 1975) - PAUL SHEWCHUK

2:50 - 3:10 (b) Fish Egg Embryonic Development and Oxygen
- EARLE BADDALOO

3:10 - 3:25 2.9 Research Needs Based on Data Gaps
- DR. PAT TONES

3:25 - 3:50 3. DISCUSSION - DR. LEONARD LILLIE (Main Issues) +
Additional Issues from All Attendees

3:50 - 4:00 4. SUMMARY (RACONTEUR) - DR. LEONARD LILLIE

4:00 - 4:05 5. ADJOURNMENT - PAUL SHEWCHUK/DR. PERCY SIMS

* Finalized Program

APPENDIX B:
WORKSHOP OBJECTIVES AND FORMAT



DISSOLVED OXYGEN OBJECTIVES WORKSHOPOBJECTIVE:

TO SHARE INFORMATION ON THE USE AND APPLICATION OF THE DISSOLVED
OXYGEN OBJECTIVE FOR WATER QUALITY CONSIDERATIONS.

FORMAT

- AGENDA AND TIME LINES
- PRESENTATION AND 3 TO 5 MINUTES FOR QUESTIONS
- PROGRAM ADVANCE FORWARD IF REQUIRED
- DISCUSSION - MAIN ISSUES (FLIP CHART) PLUS ALL ATTENDEES
- ASSEMBLY OF PROCEEDINGS - RECORD

APPENDIX C:

LIST OF ATTENDEES



ATTENDEES LIST

Mr. Earle G. Baddaloo, AE
Mr. Dave Barton, AE
Ms. Christine Brodie, AE
Mr. Gary Byrtus, AE
Mr. John Campbell, AE
Ms. Pat Cary, AE
Mr. Dave Christensen, FLW
Mr. Serge Dobko, AE
Dr. Brian Hammond, AE
Mr. J. Bryan Kemper, AE
Dr. Len Lillie, AE
Mr. Allan Locke, FLW
Mr. Ian Mackenzie, AE
Mr. Bob Martel, AE
Mr. Akio Masuda, AE
Ms. Patricia Mitchell, AE
Dr. Jim Moore, AE
Mr. Leigh Noton, AE
Ms. Janice Park, AE
Mr. Joe Prusak, AE
Mr. Paul Shewchuk, AE
Dr. H. Percy Sims, AE
Mr. Kem Singh, AE
Mr. Sam Thornhill, AE
Dr. Pat Tones, Beak Associates & Consulting Ltd.
Mr. Dave O. Trew, AE
Ms. Annette Trimbee, AE
Dr. Albert van Roodselaar, AE
Mr. Gordon Walder, AE

AE = Alberta Environment

FLW = Forestry, Lands and Wildlife